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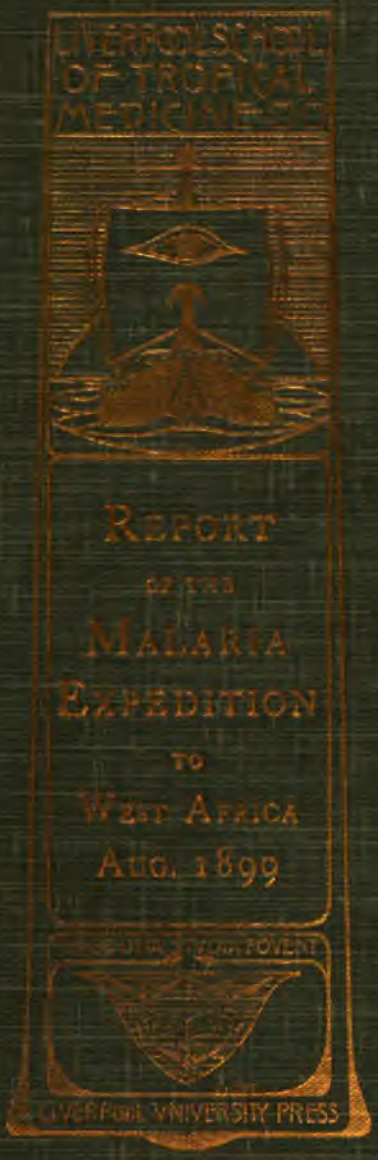

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REPORT

OF THE

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LIVERPOOL SCHOOL OF TROPICAL MEDICINE—MEMOIR II.

REPORT

OF THE

MALARIA EXPEDITION

OF THE

LIVERPOOL SCHOOL OF TROPICAL MEDICINE
AND MEDICAL PARASITOLOGY

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WITH SUPPLEMENTARY REPORTS

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TO THE

RIGHT HONOURABLE JOSEPH CHAMBERLAIN, M.P.

HER MAJESTY'S PRINCIPAL SECRETARY OF STATE
FOR THE COLONIES

WHO IN HIS OWN CITY HAS FOUNDED A UNIVERSITY

AND

DIRECTED RESEARCH TO THE ALLEVIATION OF TROPICAL MALADIES

THROUGHOUT VAST PROVINCES OF THE EMPIRE

THIS REPORT UPON THE PREVENTION OF MALARIAL FEVER

IN WEST AFRICA IS RESPECTFULLY DEDICATED

BY THE

LIVERPOOL SCHOOL OF TROPICAL MEDICINE

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OF THE

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In publishing this Report the Committee wish to express their thanks, for assistance rendered in furtherance of the objects of the expedition, to the Right Honourable Joseph Chamberlain, Secretary of State for the Colonies; to Professor E. Ray Lankester, F.R.S., Director of the Natural History Department of the British Museum; to the British Medical Association; to H. E. Major Nathan, R.E., C.M.G., Acting Governor of Sierra Leone; to H. E. Sir Frederic Hodgson, K.C.M.G., Governor of the Gold Coast; to H. E. Sir William MacGregor, M.D., K.C.M.G., Governor of Lagos; to Colonel Burke, D.S.O., Commanding H. M. Forces in Sierra Leone; to Major Norris, D.S.O., and the Officers, 1st Batt. West India Regiment, Sierra Leone; to Drs. Strachan, Prout, Henderson, Renner, Berkeley, and Chalmers, of the West Coast; and to Major G. M. Giles, I.M.S., for kindly undertaking part of the work of Mr. Austen.

The present opportunity has been taken for recording some previous observations on the subject made in India by one of the members of the expedition.

ALFRED L. JONES,
Chairman.

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REPORT OF THE MALARIA EXPEDITION

OF THE

LIVERPOOL SCHOOL OF TROPICAL MEDICINE AND MEDICAL PARASITOLOGY.

I. PRELIMINARY.

1.—Introduction.—The HÆMAMŒBIDÆ are a group of unicellular parasites of the red blood-corpuscle, found in man and in certain kinds of monkeys, bats, birds, and, perhaps, frogs. The group derives great importance from the fact that the human species are the cause of malarial fever.

We owe the discovery of these organisms to Laveran, Danilewsky, Koch, and Dionisi; and are indebted to Laveran, Golgi, Romanowsky, MacCallum, and others for our knowledge of their life-history and structure within the vertebrate hosts.

Following upon these discoveries, it remained to ascertain the life-history of the group outside these hosts; but all efforts to cultivate them or to find them in external nature were attended at first with failure. In 1883, however, King adduced a number of reasons in support of the view that gnats are connected with the propagation of malarial fever [1]. Next year Laveran expressed the opinion that the parasites discovered by him may undergo further development in gnats [2]. In 1894 Manson independently came to the same conclusion; chiefly on the ground that some forms of the parasites (gametocytes) emit certain motile filaments (microgametes) after the blood containing them is drawn from the host—a phenomenon which could be explained only by the theory that the parasites migrate into suctorial insects [3, 4]. Koch, Mendini, and Bignami have also adopted the gnat-theory of malaria on various grounds [12].

Working in India upon Manson's induction, one of us, after numerous negative experiments with several species of gnats of the genus *Culex*, succeeded in cultivating one of the human Hæmamœbidæ in two species of gnats of the genus *Anopheles* (dappled-winged mosquitoes) in 1897 [5]; and next year completed our knowledge of at least one cycle of the life-history of this group of parasites by following the development of *Hæmamœba relicta* of birds in gnats of the *Culex pipiens* type [6], and by communicating the infection from diseased to healthy birds by the bite of these insects [7]. This work was confirmed by Daniels in 1898-99 [8].

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In 1897 MacCallum had already supplied an important fact in the life-history of the group by demonstrating the sexual nature of certain forms (gametocytes) of the organisms [9].

At the end of 1898, Koch and Grassi, Bignami and Bastianelli, almost simultaneously confirmed these observations. It was found that in Italy, as in India, the human species develop in gnats of the genus *Anopheles*; and the Italian observers finally succeeded in infecting healthy human beings by the bite of previously infected insects of this kind [10, 11].

The results of these investigations have been accepted by Ray Lankester, Laveran, Manson, Metchnikoff, and others; and a full history and bibliography of the subject has been published by Nuttall [12].

To sum up; although some points of importance still require investigation, it has been shown that certain species of gnats are definitive hosts of the Hæmamœbidæ; that the parasites are conveyed from diseased to healthy vertebrates (intermediary hosts) by these insects; and that the definitive hosts of the human parasites are certain species of *Anopheles* [*Section V.*].

2. Objects of the Expedition.—As soon as these facts were ascertained it became necessary to enquire whether the discovery could not be turned to practical account for the better prevention of malarial fever. The question was theoretically examined at length by one of us in February [13], and again in May, 1899 [14]. From an early stage in his investigations in India he had noted that, so far as his studies then went, gnats of the genus *Anopheles* sometimes appeared to breed only in comparatively small and isolated pools of water—a fact which suggested that in some localities it may be possible to exterminate them without great difficulty. Unfortunately his observations had not been exhaustive enough to enable him to speak with confidence on the point; while other students of the subject had not given it sufficient attention.

Hence the Liverpool School of Tropical Diseases undertook to open a special investigation of the question; and despatched an expedition consisting of ourselves to the West Coast of Africa for the purpose. Our objects were as follows:—

(1.) To find one or more species of insects hospitable to the human Hæmamœbidæ on the West Coast of Africa.

(2.) To study the bionomics of these insects with a view to suggesting better modes of prevention of malarial fever than those hitherto known to us.

It was not proposed that the expedition should remain in Africa for more than a few weeks; and it will therefore be understood that, owing to the short time at our disposal, we were obliged to limit our investigations strictly to the matter in hand.

3. History of the Expedition.—Sierra Leone was selected for the field of the first operations.

The expedition primarily consisted of (1) Major R. Ross, Lecturer in Tropical Medicine, University College, Liverpool; (2) Dr. H. E. Annett, Demonstrator in Tropical Pathology, Liverpool School of Tropical Diseases; and (3) E. E. Austen, Esq., Zoological Department, British Museum.

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We arrived in Freetown, Sierra Leone, on the 10th August, 1899; and speedily succeeded in ascertaining that two species of gnats of the genus *Anopheles* found in Freetown are hospitable to the human Hæmamœbidæ [*Section III.*]. The rest of our time was spent chiefly in a study of the bionomics of these insects [*Section IV.*]; and we left Freetown for England on the 27th September, after seven weeks' stay in the colony.

Our observations constitute the body of this report; but before our departure from Sierra Leone we were joined by Dr. Fielding-Ould, who was despatched by the Committee of the School to continue our labours after our return. After we left, Dr. Fielding-Ould proceeded to Accra and Lagos; and his observations are given separately in the Addenda to this report.

We were also joined at Freetown by Dr. G. Van Neck from Belgium. Dr. Van Neck was unfortunately taken seriously ill shortly after our departure, and did not return until December.

4. Terminology Employed.—As regards the Hæmamœbidæ, we adopt the morphological terminology and taxonomic nomenclature already used by one of us in consultation with Professor Herdman, F.R.S. [15]. These will be found in the Discussions [*paragraph 19*]; where we consider the terminology further, and also give a summary of the life-history and classification of the parasites.

As there is no difference between gnats and mosquitoes—the latter term being merely one which is popularly employed for gnats in warm countries—and as this confusion tends to maintain erroneous notions regarding these insects, we propose to abandon the word *mosquito* and use in preference the old English equivalent *gnat*.

The terms *malaria* and *malarial fever* are unsound, while *paludism* is inexact. We may therefore venture to suggest the appellations *hæmamœbiasis* or *gnat-fever* for the disease which is the subject of this report. They will at least serve to popularise more correct notions of the malady than are implied in the word *malaria*.

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II. FREETOWN, AND FEVER STATISTICS.

5. Description of Freetown.—Freetown, the Capital of the British Colony of Sierra Leone, is situated approximately in Lat. 8° 30′ N., and Long. 13° 15′ W., on the northern shore of a mountainous promontory. Close behind the town there is a semicircle of wooded hills rising to a height of 3,000 feet above sea-level; and the town itself lies mostly on areas of level ground between them and the sea. The principal houses are built near the wharfs; but from here the suburbs reach backward between the spurs of the hills. Few houses of the town proper exist on the slopes of the hills; but numerous separate villages are found in the higher valleys above.

The soil of Freetown is derived from a red laterite rock; which lies at little depth, and is exposed in many level parts of the town, as well as in water-courses, etc.

The rainy season lasts from May until October. The average annual rainfall is 163 inches, the average humidity 75.0, and the average temperature 80.0° F. [*paragraph 6*].

1. Freetown from Mount Aureole, looking westward. Tower Hill in the middle distance, and Wilberforce Hill in the distance.

The city contained 30,033 inhabitants at the last census (1891). The population consists mostly of natives (Christians, Mohammedans, Pagans), but there is also a colony of Europeans.

2. Street in Freetown, showing ditch at the side.

The streets are open spaces between the houses, generally fringed with grass, unpaved, and undrained, except by roadside ditches; but gutters exist in the best part of the town, and occasionally elsewhere. Most of the streets are sloped, but a few are almost level.

The houses are built mostly of wood, or consist of a superstructure of wood on a masonry foundation. They are often two stories high, and are generally divided from each other by small open yards and gardens, in the manner of *villas*. As a rule the rooms are very small for tropical habitations.

There is an excellent water-supply brought from the adjacent hills in pipes.

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Surface and storm-water drainage is carried mostly in the roadside ditches, but mountain torrents on their way to the sea occasionally intersect the level areas on which the town is built.

There is no sewage drainage, nor removal system for night-soil. Deep pits, or rather wells, covered by a privy and seat, are employed. It is stated that the old pits are sometimes filled up and new ones dug; but so far as we could judge, dry earth is seldom used, except by the Europeans and troops, and the system adopted seems to be a natural kind of *septic-tank* system.

Wells for drinking-water are not generally in use.

Horses and wheeled traffic are rare. Those who do not walk are carried by native bearers in "hammocks."

The troops, which belong mostly to the West India and West African regiments, are housed much better than the civil population. Their barracks are well-built wooden structures, placed on the summits of four hills; namely, on Tower Hill (400 feet), in the middle of the town; on Mount Aureole (800 feet) and Kortright Hill (1,100 feet), to the east of the town; and on Wilberforce Hill (600 feet), some distance to the west of the town [*photograph* 1 *and Map I.*].

Civil patients are treated in the large Colonial Hospital, the Incurable Hospitals, Lunatic Asylum, etc. Military sick have their own hospitals attached to the several barracks mentioned above.

Mangrove swamps occur in some of the bays and creeks of the shore.

Collections of water suitable for the larvæ of gnats abounded in the town when we were there (rainy season). Such collections could be divided into two classes; namely, (1) collections in vessels; and (2) collections on the ground. The former occurred in tubs, pots, broken bottles, etc., in the vicinity of almost all the houses; the latter chiefly in the roadside ditches and holes in rock, and, almost exclusively, on areas of level ground.

6. Statistics.—It is usually impossible to obtain from statistics any exact information regarding the actual number of infections of hæmamœbiasis occurring within a given place and period. The reasons for this are—(1) that the vast majority of attacks are not recorded; (2) that a large number of attacks which are recorded must be mere relapses, due to infections acquired perhaps long previously and in other localities; and (3) that the microscope is not generally used for exact diagnosis. Similarly the mortality returns are apt to be vitiated, because (1) the infection has often been acquired elsewhere; (2) Europeans are frequently invalided when seriously ill; and (3) deaths of cachectics are often ascribed to immediate causes, such as pneumonia and dysentery.

Military returns, though they are sometimes thought to be more trustworthy, are open to the same objections. Many soldiers do not come to hospital at all for slight attacks of fever; while others are frequently only "detained" in hospital for brief treatment, without being "admitted"—that is, entered in the returns. Thus we were informed of an instance in which only one quarter of the cases of fever which came to hospital had been "admitted" and recorded.

The *absolute* figures are therefore not trustworthy; but, by supposing the ratio of error to be always constant, we may derive some useful *comparative* information regarding the amount of fever prevalent in different places, and at different seasons.

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We will content ourselves by giving a table extracted from the work of Major L. M. Wilson, R.A.M.C. [16]. The statistics are based on admissions to hospital among the troops in Sierra Leone during seven years (1892-98), and on the meteorological returns of the same period.

Average monthly Admission rates among the troops, and average monthly Rainfall, Humidity, and Temperature in Sierra Leone during seven years (1892-98).

Month.	Average admission rate per 1000.		Average Rainfall in inches.	Average Humidity.	Average Temperature in shade.
	Non-European.	European.			
January	52	93	.80	70.2	80.8
February	47	99	.86	68.2	81.0
March	63	59	1.24	67.7	81.7
April	86	106	4.36	67.3	81.6
May	99	225	14.08	75.3	80.3
June	128	347	18.62	77.1	79.2
July	171	413	33.34	83.0	78.3
August	116	281	38.96	84.0	77.7
September	91	173	29.85	82.2	78.8
October	67	121	14.63	79.1	79.4
November	72	125	5.41	75.0	80.5
December	64	92	1.26	71.9	80.7
Annual ...	1056	2134	163.41	75.0	80.0

Judging from these figures Wilson remarks, "The largest number of cases occur in the middle of the rainy season." Though many of the cases recorded in the rains may be relapses due to wettings, chills, etc., this can scarcely account for the quadruplication of the admissions shown in the table; and it would therefore appear that the *period of fresh infections* sets in (or at least increases) with the rains, and ceases (or at least diminishes) with them.

Wilson also thinks that "The white troops suffer more in proportion than the black." He gives the annual average death-rate of the white troops from malarial fever at 42.9 *per mille*, as against 5.9 *per mille* for the black troops. Similarly, he thinks that "Each battalion of the West India Regiment suffers exceptionally from fever the first year of its service on the coast." Such differences point rather to variations in *immunity*, than to variations in *frequency of infection* in the groups concerned.

It is hardly necessary to compare these statistics of Sierra Leone with similar figures for many other stations in the empire; but it will be instructive to give some ratios taken from the Annual Report of the Sanitary Commissioner with the Government of India for 1897.

For the whole European Army of India during that year the admissions *per mille* of strength for malarial fever were 420.1; and the deaths *per mille* were 1.0—far below the

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figures for Sierra Leone. But in the most malarious stations the admissions *per mille* reached 1500; and the deaths, 6.0, excluding "remittent fever."

For the whole Native Army of India the annual admissions *per mille* were 362.8; and the deaths *per mille*, 1.7. But in the most malarious stations the admissions reached 2230, and the deaths, 6.8 *per mille*.*

It is obvious that Sierra Leone is much more malarious than India taken as a whole is; though perhaps not much more so than some places in India.

A study of the Indian statistics shows, moreover, that the admissions for the disease in that country have, roughly, the same dependence on rainfall as they have in Sierra Leone—that is, of course, not on the total amount of rainfall, but on its seasonal variations. Indeed, some of the most malarious military stations in India (Peshawur, Delhi, Lahore, etc.) have a small total rainfall.

* As a rule, natives in India suffer more than Europeans do—at least to judge by statistics.

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III. HÆMAMŒBIDÆ IN FREETOWN.

7. The Hæmamœbidæ in Intermediary Hosts.—Duggan studied the human parasites of Sierra Leone some years ago [17]. He found only *Hæmomenas præcox* (with one exception—a case of *Hæmamœba vivax*). *Hæmomenas malariæ* was not observed by him. He says "Crescents were found in varying numbers in most of the cases." His results are based on the study of "about 400 cases."

Our own examinations of the blood of patients were made solely with a view to obtaining a basis for further researches as to the definitive hosts of the parasites; and it will be understood that we contemplated no morphological or pathological studies. Search was confined almost entirely to soldiers, few cases of fever among the civil population being procurable by us for study. The barracks at Wilberforce and Tower Hill afforded excellent fields for investigation. It should be noted that the men in these barracks belonged to West India regiments—that is, were natives of the West Indies who had been serving in Sierra Leone only for a short period.

The troops at Wilberforce had arrived there some months previously from a very malarious part of the colony, and continued to suffer severely from fever. They numbered about 320 men. We were informed that out of these no less than 195 men had come to hospital for fever in one month (July); although, as most of the men were not ill enough for admission, the "admission" rate was much lower. We examined the blood of a large number of the men, both in hospital and out of it, and estimated that the parasites were to be found in about a quarter of them taken at random. The species found were all of those now recognised in most parts of the world. *H. malariæ* was the commonest; but cases of *H. vivax* and *H. præcox* also abounded, being about equal in number. Cases of double infection were frequently observed. The prevalence of the disease was at its height at the time of our arrival, although quinine had been and was being sedulously given both for treatment and prophylaxis; and it was evident that such a number of cases could not be attributed alone to relapses, but that fresh infections were occurring at the time.

At Tower Hill there was much less fever. We attempted no estimate of the number of men in whom parasites could be found. Parasites could, however, be easily detected in the hospital cases. They belonged almost exclusively to *H. præcox*; though two or three cases of *H. malariæ* and *H. vivax* were observed.

There were very few cases among the troops on Mount Aureole and Kortright Hill. Of three cases examined in the hospital on Mount Aureole, one contained *H. malariæ*; another the melanin of *H. malariæ*; while the third was negative on a cursory search.

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The morphology of these Hæmamœbidæ presented no differences from the accepted standards. One of us has been inclined to admit two varieties of *H. vivax*, one with fine light brown pigment, and one with fine black pigment. Both were observed in Freetown; but the latter only in one case.

We were much struck by the absence or paucity of crescents (gametocytes) in cases of *H. præcox*. This fact will be discussed later [*paragraph 19*].

We found *H. danilewskii* of the normal type in a few small birds; but *H. relicta* was not seen by us.

We wished to examine the blood of a large number of the civil population in order to estimate the percentage of them in which the parasites are to be detected; but found such an investigation impracticable.

8. Methods for ascertaining Definitive Hosts.—The long researches of one of us in India, followed by those of Koch, Daniels, and the Italian investigators, have given us a very exact knowledge of the life-history of the Hæmamœbidæ in gnats, and have shown us how to detect them in the insects with ease and certainty. It has been noted that in inhospitable species of gnats the ingested parasites perish within the stomach cavity; whereas in hospitable species the zygotes escape from that cavity and develop in the tissues, ultimately giving rise to blasts which are found in the juices and salivary glands of the insect. Hence to incriminate a given species of insect with regard to the human Hæmamœbidæ, it is necessary only to find the parasites within that species. In short, the method to be adopted is precisely that used in ascertaining alternative hosts for any other metoxenous parasite, such as Cestodes and Filaridæ, for instance. Care only is required to determine for certain that the parasites found in the gnats were derived from human beings, and not from other vertebrates. It is not necessary actually to infect human beings from infected gnats, because the general law that infection can be so produced has already been sufficiently established.

Hence a given species of insect is incriminated simply if we succeed in finding the parasites—

(1) in insects bred from the larva and fed on infected persons.

(2) in any insects fed on infected persons—provided that the zygotes found in the insects are of the proper stage of growth; or

(3) in a large percentage of insects caught in a chamber where an infected person lives—provided that the circumstances exclude the possibility of the insects having become infected from other vertebrates.

9. Definitive Hosts in Freetown.—Our first object being the search for definitive hosts, we propose to record our operations in this connection in some detail.

For the reasons given in paragraph 22, suspicion was already strongly excited against all species of gnats of the genus *Anopheles*; and, accordingly, we began by searching for these insects. Two species were found almost at once, under the following circumstances.

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Dr. Berkeley, medical officer of the Lunatic Asylum at the eastern suburb of Kissy, informed us that there had been a small outbreak of fever among the permanent inmates of that institution. Three persons had been attacked; one had died, one had recovered, and one was convalescent. He was also good enough to bring us a number of gnats which he had caught within the institution. They proved to belong, almost all of them, to *Anopheles*; and were of two species, one a small species which we have named *A. funestus*, and the other a larger species called *A. costalis*, Loew. The former were by far the more numerous. [*Addendum I., Plate V.*]

The insects brought by Dr. Berkeley were dissected and examined. In one a single characteristic zygote containing the melanin of *H. vivax* was found; and since the melanin of this species is typical of it, it was scarcely open to doubt that the zygote had been derived from that human parasite.

No further positive results, however, were obtained from this locality. No fresh cases of fever occurred, while we failed to find parasites in a large number of the *Anopheles* subsequently brought from the asylum. It was, however, interesting to observe these insects in the building. Large numbers of the small species were found gorged with blood and seated asleep in their characteristic attitude on the walls. They were most numerous on the ground floor and in the sleeping chamber of the inmates—who were not provided with mosquito nets. Few other gnats were present.

In the meantime our attention had been called to the fever so prevalent among the troops at Wilberforce. On searching the barracks and hospital we found a considerable number of the large variety of *Anopheles*, namely, *A. costalis*, already observed in small numbers at Kissy. As at the asylum, they were seen gorged and asleep in their characteristic attitude on the walls of the buildings, especially in dark corners, and were easily captured in test-tubes. Some were so excessively gorged that they had been evidently willing to fly only to the nearest part of the walls, just over the bed-heads of the soldiers on whom they had been feeding; and those which were at once examined were found to contain human blood—or at least blood microscopically indistinguishable from human blood.

The men—of whom about twenty slept without nets in each barrack—complained of being bitten by these insects at night, but added that they were occasionally annoyed also during the day, especially toward evening. It should be added that no other species of gnat were present within the barracks. During our stay in Freetown we must have caught or obtained at least two hundred gnats from these buildings, but only in a single case—a *Culex*—did the captures prove to be other than *A. costalis*. We noted also that there were absolutely no vertebrates other than human beings within or in proximity to the barracks. Cattle, dogs, cats, bats, monkeys were absent, while, owing to the buildings having been newly erected, there were not even sparrows, lizards, etc.

The *Anopheles* caught by us in test-tubes—almost all of them females which had evidently gorged themselves on the men during the preceding night—were reserved for microscopical examination. They were kept alive for 48 hours or more, until their meal of blood had been so far digested or voided as to permit an easy examination of the tissues of the stomach; and were then killed and dissected—the stomach, the thorax, and the salivary glands being especially

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scrutinized. During our stay, altogether 109 fed female *Anopheles* caught within the Wilberforce Barracks were examined in this manner.

It has been stated [*paragraph 7*] that Hæmamœbidæ of all three human species had been found in about 25 per cent. of the soldiers at Wilberforce. It was therefore to be expected, if the *Anopheles* caught in the barracks were an hospitable species, that the parasites should be found also in a large percentage of these insects. And this proved to be the case. Out of the 109 insects examined the parasites were detected in 27.

The parasites were in all stages of growth; from the very youngest zygotes, evidently derived from the last meal made by the host; to the mature zygotes derived from previous meals, and the blasts lying in the salivary glands ready to produce fresh infections of human beings. We even judged it possible, in some of the dissections, to distinguish the different species of the parasites by their morphological characters [*paragraph 10*]. The following list, giving the serial number, and results of examinations of each insect in which the parasites were found (the negative insects being omitted) will be instructive :—

No. 4. Three nearly mature zygotes. Species unknown.
„ 8. One very small zygote, apparently *H. malariæ*, among stomach cells.
„ 12. Eight nearly mature zygotes. Species unknown.
„ 13. Six mature zygotes. Species unknown.
„ 14. Four very small zygotes, evidently of *H. vivax*.
„ 17. Several mature zygotes, one containing melanin, probably of *H. vivax*. Also empty capsules. Salivary glands loaded with blasts in cells and ducts.
„ 21. Eleven empty capsules (old) attached to stomach. One half-grown zygote. Salivary glands packed with blasts within capsule, cells and ducts.
„ 23. Eight very small zygotes of *H. malariæ*.
„ 29. Ten zygotes of *H. malariæ* of 3-4th day.
„ 31. Several large zygotes.
„ 32. Empty capsules. Blasts in salivary cells and duct.
„ 43. Three very young zygotes of *H. præcox*.
„ 56. Four young zygotes of *H. vivax*.
„ 57. Two young zygotes of *H. malariæ*.
„ 61. Several very young zygotes of *H. præcox*.
„ 62. One medium zygote of *H. vivax*.
„ 63. Several nearly mature zygotes, probably *H. malariæ*.
„ 65. Several smallish zygotes of *H. malariæ*, and one very young one of *H. vivax*.
„ 71. Several medium zygotes of *H. malariæ*.
„ 76. One empty capsule. A few blasts in one lobe of gland.
„ 79. One medium zygote with dark pigment.
„ 84. Three mature zygotes.
„ 89. One empty capsule. No blasts found (poor dissection).
„ 91. Six mature zygotes.

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No. 92. Very numerous large zygotes, probably *H. malariæ*.

„ 99. Several empty capsules. Numerous blasts in blood, and a few in cells of salivary gland—none in ducts.

„ 108. One nearly mature zygote.

It is possible that the parasites may have been overlooked in some of the gnats examined. That a larger percentage of the gnats should not have been infected, and that more zygotes should not have been found in them, was to be expected from the old nature of most of the fever cases among the men [*paragraph 19*], and from the constant use of quinine by the medical officer.

The facts obtained, however, removed all possibility of doubt as to *A. costalis* being hospitable to the human parasites; and it was no longer necessary to undertake formal feeding experiments. Indeed the condition of things found in the Wilberforce Barracks amounted to an experiment of this kind being performed by nature herself under our eyes. This was the more fortunate as we experienced great difficulties in the way of actually feeding gnats on infected persons in a satisfactory manner. Nevertheless a few such experiments were performed.

On the 17th August, five small *Anopheles* (*A. funestus*) caught at Kissy, were fed on a case containing a few *H. malariæ*. The insects had been naturally fertilized and fed when caught, but had been kept for some days until they had digested their meal and had laid their eggs. They were then fed again *in test-tubes* on the case referred to, and were kept for another two days before being examined. Two yielded bad dissections, and one died before its meal of blood was digested. The fourth was negative. The fifth was dissected on the 19th, and was found to contain three very young zygotes with pigment identical with that of *H. malariæ*.

A few days later, one large *Anophele* (*A. costalis*), also caught by hand and previously naturally fertilized, fed, and kept in the same manner as the preceding, was re-fed on the same case. Two days afterwards several young zygotes containing the melanin of *H. malariæ* were found in it.

In both these successful experiments the insects concerned belonged to large batches of *Anopheles* procured from a building where there was no fever; and numbers of insects of both batches had been examined and found free from parasites. Judging from this fact, and from the *size of the zygotes found*, there could be no doubt that the latter had been derived from the case of *H. malariæ*. It should be carefully noted, however, that both these insects had evidently been fertilized before they had been caught, and had indeed each laid a batch of eggs before the experiments.

The military medical authorities now put a stop to our feeding any gnats, except those bred from the larva, on their cases. As it took us some weeks to obtain *Anopheles* in this manner, and as we could then only feed the insects in a very unnatural manner, that is, in tubes, our experiments in this line were practically arrested.

Altogether eighteen *Anopheles*, mostly of the large variety, all of them bred from the larva, and some of them bred from the eggs of *Anopheles* caught at Wilberforce, were applied in test-tubes to the skin of patients containing a few *H. præcox* (crescents) and *H. malariæ*, and *taking quinine*—no better cases being available. Being isolated in test-tubes when fed, none of these insects

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were fertilized, while they could not be induced to feed copiously. All proved negative as regards the parasites. As, however, it was already certain that all the insects belonged to hospitable species, this result was interesting as tending to show that *cultivation experiments may fail if not performed under natural conditions.* The subject is discussed later [*paragraph 20*].

After our departure, Dr. Fielding-Ould examined numerous *Anopheles* caught at Wilberforce, and in the houses of natives suffering from fever, and found the parasites in 18 %. His observations on *Culex* were negative.

We made no observations on *Culex* or other insects.

We conclude that both *Anopheles costalis* and *Anopheles funestus* are hospitable to the human Hæmamœbidæ. We think that *A. costalis* is hospitable to all three of the human species; and *A. funestus* certainly to *H. malariæ*, and probably to *H. vivax*. But we made no observations regarding the connection of the latter with *H. præcox*.

10. The Hæmamœbidæ in the Definitive Hosts.—The stages of the human parasites in *Anopheles* are essentially the same as those of *H. relicta*, first described by one of us in a gnat of the *Culex pipiens* type—a fact already recorded by Koch and the Italian observers. In Plates I., II., and III. we give a series of photographs of all these Hæmamœbidæ in the gnat.

The following small differences between the human species and *H. relicta* were noted by us :—

(1.) The capsule of the zygotes of the human species is somewhat thinner; so that the youngest zygotes are more difficult to detect, and sometimes rupture under pressure of the cover-glass—a thing which rarely happens in *H. relicta*.

(2.) The mature zygotes seem to contain more blasts than do those of *H. relicta*.

(3.) The melanin appears to remain longer in the human species.

(4.) The blasts are shorter and thicker, and less bent and twisted, than those of *H. relicta*—but differences in the strengths of the salt solutions used may account for this.

(5.) In the human species the blasts tend to lie in the salivary cells in bundles, like bundles of faggots, and not irregularly like those of *H. relicta*—at least this was very noticeable in two of the gnats, numbers 17 and 99.

(6.) Owing to the dilatation of the proximal ends of the salivary ducts in *Anopheles*, the blasts can be more easily distinguished within these channels.

It is important to note that, though elements like those provisionally called "black spores" by one of us were frequently seen in the Freetown *Anopheles*, they were never detected within the capsule of the zygotes [*paragraph 24*].

The young zygotes of *H. vivax* were always immediately recognisable by the numerous minute granules of light brown melanin which they contained. The youngest zygotes were, in fact, almost identical in appearance with the mature gametocytes in the human blood. As the parasites advance in growth, the melanin seems to decrease in quantity and become slightly paler; but it was sometimes still to be found even in the most mature zygotes—which, moreover, were of very large size, and contained very numerous blasts.

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The zygotes of the other two species contained fewer and much darker granules. In the youngest ones we considered we could distinguish between the melanin of *H. malariæ* and that of *H. præcox*; the former possessing large and small granules of a dark brown colour, mixed together; the latter possessing only large black granules.

Our studies were not sufficiently exhaustive to enable us to speak regarding other differences noted by the Italian observers. Nor had we time to examine cytological details—a thing to be regretted, because the Romanowsky method does not seem to have yet been correctly applied to the study of the nuclear changes in the zygotes. We easily noted, however, the structures first described in *H. relicta*; namely, the alveolar, vacuolated appearance of the zygotes; the denser chromatoid granules; the division of the parasites into 8—12 meres, giving rise to spherical blastophores carrying blasts in a manner recalling spermatogenesis; and the minute spherical enlargements often attached to the immature blasts. We observed also that in the human species, as (to a less degree) in *H. relicta*, zygotes which are little more than half grown, often contain apparently mature blasts.

In several insects many full-sized zygotes appeared not to have ripened—that is, did not contain blasts; although others containing blasts were found associated with them.

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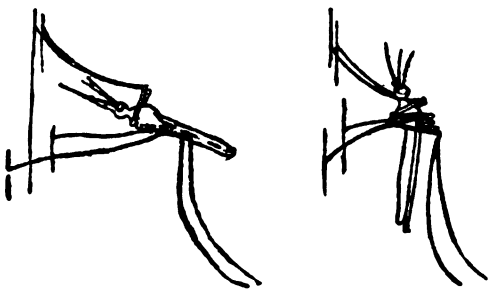
IV. BIONOMICS OF THE CULICIDÆ IN FREETOWN.

11. Differences between *Culex* and *Anopheles*.—Our next duty was to study the habits of the inculpated *Anopheles* with reference to the prevention of gnat-fever. We propose to give our bionomical observations here,* and to reserve a description of the insects themselves for the Addenda.

In view of the particular connection which seems to exist between *Anopheles* and gnat-fever, it is important to possess information sufficiently simple to enable anyone to distinguish between them and the common gnats of genus *Culex*. Such points of difference have already been recorded by one of us as the result of his observations in India [14]; and we were able to assure ourselves that the same differences hold also in Freetown.

(1). *Adults*.—The principal zoological distinction between *Anopheles* and *Culex* is that the *palpi* of the female are long in the former and short in the latter. But this is of little assistance to those who are not entomologists, and who may not know what the palpi are. Fortunately there is a more striking difference—one which can be perceived by anyone at a glance—in the *attitude* adopted by the respective insects when seated on a wall. In *Anopheles* the axis of the body is almost vertical to the wall; in *Culex* it is parallel to the wall. Popularly put, the *Anopheles* may be said to stand on its head, with the point of its tail projecting outward; while the tail of *Culex* points downward, or even a little toward the wall.



3. *Anopheles* and *Culex*.

Another noteworthy point of difference is the general *shape* of the body. In *Anopheles* the head and thorax are comparatively small, while the long palpi are held in contact with the proboscis. This gives the insect a peculiarly elegant fusiform shape—like that of a humming-bird moth; while the proboscis looks like a long thick beak. On the other hand, *Culex* has a thick ungainly thorax, and a thin bare proboscis. In short, the appearance of *Anopheles* suggests that it can fly further and more rapidly than *Culex*.

Thirdly, the wings of *Anopheles* are generally spotted along the anterior edge (to use popular

* It should be clearly understood that our remarks apply only to our own observations. We cannot answer for facts in other localities.

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language), while those of *Culex* are generally plain. There are exceptions to both these statements; but the rule holds good in Freetown, and also, according to the observations of one of us, in India.

The eggs of *Anopheles* have a peculiar boat-like shape, while those of *Culex* are oval or lanceolar.

(2.) *Larvæ.*—Here too, very fortunately, there is a marked difference. The *tracheæ* of *Culex* terminate in a long buoy-like breathing tube which projects, sometimes to a great length, above the tail fins. On the other hand, the tracheæ of *Anopheles* merely terminate just above the tail fins, in two apertures which are nearly flush with the back.

Apparently owing to these facts, the *attitude* also of the larvæ of the two genera is different: those of *Culex*, when at rest, hang suspended head downwards by the attachment of their breathing tube to the surface of the water; those of *Anopheles* float flat on the surface like sticks.

When disturbed, *Culex* larvæ immediately leave the surface and wriggle to the bottom of the water, floating up again a few moments afterwards by the buoyancy of their air-tube. The movements of *Anopheles* larvæ are quite different. They move on the surface of the water with a few peculiar backward jerks, followed by a pause; and sink to the bottom only when much molested.

Lastly, *Culex* larvæ live mostly in *artificial* collections of water, while *Anopheles* larvæ prefer *natural* collections—a point, however, which requires special consideration.

12. Breeding Places of *Culex*.—In Freetown, as in all collections of houses, there are to be found in the vicinity of human dwellings innumerable tubs, pots, shards, etc., in which a little rain water or household slop water collects. In almost all such in Freetown—tubs, pots, buckets, cisterns, empty oil-tins, biscuit-tins, sardine-tins, gourds, flower-pots, broken pottery, crockery, and bottles, even in unbroken bottles thrown uncorked on heaps of refuse—we found *Culex* larvæ. The only condition necessary to their existence appeared to be an ounce or more of water preserved from desiccation or leakage. Occasionally, also, the larvæ were found in hollows in rocks, pools by the side of roads, and even in small runnels of water. Very numerous larvæ of a gnat of the *C. tæniatus* type were observed in hollows in rocks on the top of Signal Hill (400 feet), near the Signal Station (occupied); also some of the same larvæ, in a hole in rock hundreds of yards from human habitations.

Similar facts have been always observed by one of us in India. Drains, ditches, and small ponds must be added to the haunts of *Culex* larvæ; but, as a rule, vessels of water near houses appear to be their favourite habitations.

13. Breeding Places of *Anopheles*.—We made a very elaborate search in Freetown for *Anopheles* larvæ. Every part of the town shown in a map which was given to us was carefully examined; and wherever a breeding place of *Anopheles* was observed it was entered on the map [*Map II.*].

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We recorded the following observations :—

(1.) *Anopheles* larvæ were never found in vessels of water, except in a single instance—a tub.

(2.) A mangrove swamp fringing a part of the coast (Aberdeen Creek), far from human habitations, contained no larvæ, although there were numerous fresh-water pools on the edge of the dry land. Small fish abounded in the swamp.

(3.) Part of a large swamp below Wilberforce Hill, and also one at Kissy, was examined by ourselves, assisted by several natives. Water lay to the depth of an inch or two between clumps of grass, on a basis of flat rocks. Habitations were distant. No larvæ found.

(4.) Owing to the hilly nature of Freetown there are not many ponds or large pools. Such as there are contained no larvæ—although in several of them there were no fish.

(5.) Rapid streams contained no larvæ.

(6.) Pools left drying after rain in watercourses, or other positions liable to scouring by heavy rain, seldom contained larvæ—at least at the season when we were at Freetown.

(7.) Shallow puddles of rain-water, apt to dry up between the showers, seldom contained larvæ.

(8.) Puddles which lasted from shower to shower, but which were not liable to be scoured out by heavy rain, generally contained them.

(9.) Pools on soil or rock fed by water oozing from the ground, and small slow runnels of water amongst herbage, usually contained large numbers of larvæ—unless liable to scouring.

Altogether we counted within the area of the map about one hundred principal pools containing *Anopheles* larvæ.

Generally speaking, we found the larvæ in *small permanent pools not liable to scouring*. We did not find them in *vessels, evanescent pools, pools liable to scouring, large collections of water, and running streams.*

It would appear, then, that the larvæ require certain conditions, namely, security from (1) desiccation, (2) scouring. To these should perhaps be added (3) security from small fish.

4. A large *Anopheles* pool in roadside ditch.

As may be surmised, then, *Anopheles* pools were not found on *sloping ground*—where puddles either dry up very quickly or are apt to be scoured out by heavy showers. On the other hand they were frequently found on *level ground*. We did not find them on the hills surrounding Freetown (though they were probably present in a few places); we did find them frequently in the flattest and lowest parts of the town.

The majority of the *Anopheles* pools were found in the ditches by the side of roads and in certain localities where many small streamlets ooze from the bases of the hills after rain. Others existed in the course of the newly-made railway. Few were observed in the yards and gardens of houses.

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5. Large *Anopheles* pool produced by railway embankment.

Most of them contained green water-weeds, and many tadpoles and frogs; but none contained fish.

In size they varied from a few square inches in area to several square yards.

It is important to note that in no case did we find *Anopheles* larvæ in pools which, though otherwise suitable for them, were distant from human habitations. We must add, however, that we did not examine many such, except in the swamps referred to above.

In considering these facts it is necessary to remember two things. *First*, Freetown is a hilly place with a low subsoil water—circumstances which limit the number of surface puddles of all kinds, and especially of permanent stagnant puddles. *Secondly*, when we carried on these investigations it was the height of the rains; that is, heavy showers usually fell several times a day. This, in a hilly country, must act in opposite ways as regards surface pools. It constantly replenishes all these pools, but at the same time it constantly scours out those which exist in watercourses and on sloped surfaces. A different state of things may prevail as the showers become less frequent toward the end of the rains; the smaller puddles will then tend to dry up between the showers, while those formerly subject to scouring may now cease to be so, and may become habitable for *Anopheles* larvæ. Thus we thought it likely that after the rains they may be found in the numerous pools which will then be left in the beds of the drying-up watercourses where, during the rains, they would be swept away.

Hence it is not advisable to generalize too much from these observations, regarding either the frequency of *Anopheles* puddles in other places, or even in Freetown at other seasons. In some places the puddles must be more numerous; in others less numerous; while in Freetown itself their number and position probably change from season to season.

6. Collection of small *Anopheles* pools.

14. Distribution of *Anopheles* in Freetown. Owing to difficulties in the way of catching gnats in private houses, we could not make exhaustive studies of the distribution of the adults in various parts of the town. The following facts, however, were observed:

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(1.) *A. costalis* was found all over the low-lying areas examined by us. That is, the larvæ which yielded this species were found in all these areas; though it was much more difficult to obtain the adults. The adults were most numerous in the Wilberforce Barracks (600 feet); but were also obtained in other parts of the town, as far east as the suburb of Kissy. No adults were ever seen in the barracks and officers' quarters on Tower Hill (400 feet); although there were numerous breeding-pools only 500 yards to windward. None were found in the barracks on Mount Aureole (900 feet); although pools lay all round the base of the hill.

(2.) *A. funestus* was restricted entirely to the eastern part of the town; we never found a larva nor an adult of this species west of Government House. Not one was seen in Wilberforce Barracks, where *A. costalis* was so common. Individuals were caught in a house in the town where some cases of fever had occurred; at Leicester, a village high among the hills; and at some other points. The larvæ were common in pools in the eastern quarters, at Kissy, and other spots.

It is curious that while only the large species occurred at Wilberforce, it was *almost* entirely the small species which was found at Kissy.

15. Bionomics of *Anopheles* Larvæ. We made the following observations:

(1.) *Eggs.*—These are *boat-shaped*, like those of *Anopheles* observed in India. They appear to be laid singly on water; but cohere by their ends, forming typical triangular patterns; and also adhere to floating objects, the sides of the vessel, etc. We observed no facts indicating that they are ever laid on solid surfaces. *In vitro* they take about 24 hours to hatch; but the period is probably much shorter in puddles.

(2.) *Duration of larval stage.*—This depends on temperature and amount of food. Under natural conditions it may probably be only three or four days; but under unfavourable conditions (cold, overcrowding, absence of food) it may certainly extend to weeks.* There are reasons for thinking that development is much hastened by bright weather, in order to enable the imago to hatch out before desiccation of the containing puddle.

(3.) *Food.*—The larvæ were frequently watched floating on the surface and feeding on filaments of water-weed—amongst which they often entangle themselves. On dissection, the intestine was found crammed with these filaments. It was observed that *in vitro* the larvæ scarcely grow in size unless they are given large quantities of water-weed—which they dispose of very rapidly. On the other hand, larvæ were often caught in puddles in which no green vegetation could be seen. They may eat other food, but it would seem as if water-weeds constitute their favourite diet. It was also noted that they obtain shelter among these weeds from the current running through the pools during or after rain.

(4.) *Enemies.*—No observations could be made under this head; but we often found many frogs and tadpoles in the breeding-pools, apparently living at peace with the larvæ.

(5.) *Effects of desiccation.*—During most of our stay in Freetown heavy showers fell several

* One of us kept *Culex* larvæ alive for two months in a bottle in the cold weather in India.

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times a day, so that the larvæ could live secure from desiccation in all but the most evanescent puddles. In September, however, there was a complete break in the rains, lasting three days. A large number of the pools, even many of those containing water-weed, and those fed by springs during rain, dried up completely. The question whether the larvæ had the power of living in the mud at the bottom of the pools could now be tested by direct observation. The break in the rains was followed by heavy showers, which immediately refilled all the puddles. Had the larvæ continued to exist in the mud, they would now have emerged again. As regards the puddles in which the mud had completely dried, this was not the case. No larvæ at all were found in them for at least two days after the rain had refilled them. After that interval larvæ again appeared; but they were very small ones, evidently just hatched from the egg. On the other hand, it was frequently observed that if the mud did not become completely dry, the larvæ would emerge into active existence after another shower. These observations were supported by some experiments *in vitro*; and we therefore conclude that the larvæ can withstand partial, though not complete, desiccation.*

(6.) *The same puddles constantly occupied.*—We have suggested [*paragraph 13*] that the position of the breeding pools may change according to the seasons; but while we were in Freetown there was no change of season, and we generally found *Anopheles* larvæ in the same puddles—namely, in those which were suitable for them. Thus, of two puddles lying close together, one would never contain larvæ, and the other would always contain them. The explanation of this probably is that the larvæ perish in the unsuitable pools, or that the adults generally return to the same pools in order to lay their eggs. It seems likely that the adults generally lay their eggs in the pools in which they themselves were bred; and that the insects thus learn by experience the places most suitable for them.

(7.) *Detection.* It is easy to overlook *Anopheles* larvæ unless they are searched for in a bright light.

(8.) *Pupæ.* The pupæ of *Anopheles* seem to be smaller than those of the commoner species of *Culex*. They require about 48 hours to reach maturity *in vitro*; perhaps less in natural conditions.

16. Bionomics of Adult *Anopheles*. (1.) *Hatching.*—The adults generally hatch out in the evening; but their exit seems often to depend on the meteorological conditions of the moment, and appears to be delayed by rainy and windy weather.

(2.) *Food.* They can easily be kept alive in glass cages, test-tubes, bottles, etc. We kept some in this manner for a fortnight, and could doubtless have kept them longer if we had wished to do so. We were able to confirm Bancroft's statement [18] that gnats feed on bananas; but they seem to prefer the fresh fruit. During the day the insects remained at rest on the walls of the cage; but in the evening began to fly about and to walk over the fruit, plunging their proboscis into it in many places, so that the banana was sometimes covered with the gnats, both

* One of us reared adults from full-grown larvæ kept on damp blotting-paper (in India); but found that the young larvæ died when kept under these conditions.

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male and female. They also drink water frequently, and can often be seen to be distended with the fluid. Raw meat was offered to them, but they could not be observed to touch it. Earth placed at the bottom of the cage seems to be suitable for them.

According to the accounts of the soldiers at Wilberforce, they bite almost entirely in the evening and night, but have been known to feed on men during the day. They can certainly be fed on men artificially during the daytime, simply by placing them in test-tubes and then applying the mouth of the tube to the skin. The stomach can be observed to become distended in from one to two minutes or more; after which the insect continues to suck, but commences to evacuate by the anus serum containing a small percentage of red corpuscles. *Culex* voids only a clear fluid under the same circumstances. The insects sometimes continue sucking like leeches for five or ten minutes, voiding blood all the while; but at other times soon withdraw the proboscis and then try another spot. It was noted, however, that *Anopheles* fed in this manner, even after they had remained sucking for five or ten minutes, never showed any great distension of the abdomen; while the contents of the stomach still remained for some time transparent and red as seen through the scales of the living insect. Moreover, in these cases the meal was generally digested or voided within about 24 hours.

On the other hand, *Anopheles* which had fed themselves under natural conditions generally presented a very different appearance. They were enormously distended; while the contents of the stomach were thick, opaque, and black, and sometimes did not disappear for three days. The only inference is that, under natural conditions, the insects which can manage to do so gorge themselves over and over again during the night—probably from the same subject.

(3.) *Propagation.*—We also observed that while naturally-fed gnats *invariably* laid eggs after two or three days, those which had been bred from the larvæ in captivity, and had then been isolated and fed in test-tubes, *never* did so, although before being isolated they had long been in company with males. The inference is that fertilization takes place only after the female has been fed.

We noted also that, in a cage where many male and female gnats, both *Culex* and *Anopheles*, were kept together for weeks, eggs were never laid—although the insects were fed as described on bananas, and the cage contained water for them to lay their eggs in. It seems, then, that a meal of blood is necessary before fertilization.

Lastly, we observed that previously fed and fertilized insects would lay a second batch of eggs after a second meal of blood, without a second fertilization; but never laid a second batch of eggs without a second meal of blood. That is, one fertilization suffices for several batches of eggs, but one meal of blood for only one batch of eggs.

These observations are wholly in accord with the results of the prolonged study of many kinds of gnats made in India by one of us; and it therefore seems likely that the following law is likely to hold good for the *Culicidæ* which feed on men—at least for the commoner species:—

Although these gnats can live indefinitely on fruit and perhaps juices of plants, the female requires a meal of blood, both for fertilization and for the development of her ova. In other words, *the insects need blood for the propagation of their species.*

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Blood was never found in male *Culicidæ* in Freetown—according with the general law.

(4.) *Haunts.*—The large majority of *Anopheles* caught by us in dwellings were females which were generally much gorged, and, if fed at all, were invariably fertilized; in other words, the males and unfed, or only slightly fed, females did not generally remain in the houses during the daytime, or if they did remain, kept in the roofs or other dark places where they were little observed. On the whole, we think that only those females which are so gorged that they cannot fly far remain in the houses during the day. We observed that if a cage full of *Anopheles* was disturbed in the daytime, the insects always struggled toward the light as if to fly out from the windows; and several which escaped from the cages actually did so. On one occasion a large number escaped from their cage during the night in the rooms occupied by one of us—none of them could be seen next morning.

Yet we may be quite sure that both the males and the unfed females haunt the houses during the night. The invariably fertilized condition of the gorged females caught in the houses shows that the males must be present in the houses when the females feed—since the latter are often so much distended after feeding that they are obviously unwilling to fly even a few feet from the bed of their victim; in other words, fertilization must take place within the houses. The unfed females must, of course, resort to human habitations during the night in order to obtain their food at all.

These facts would seem to indicate that in Freetown, in the rainy season, the *Anopheles* resort to the houses during the night, but that all except the gorged females live elsewhere during the daytime—possibly sleep in the trees and shrubs. The point is of interest as tending to show that large numbers of *Anopheles* may be present in a dwelling during the night, without it being easy to find them during the day.

It should, however, be added, that in India males and unfed females were often found in the houses in large numbers by one of us. Possibly different species have different habits in this respect.

Several old residents of the country informed us that gnats are usually very prevalent in the presence of much vegetation—especially long grass and undergrowth. Though it is difficult to see how such can favour the larvæ, we can understand that much vegetation can shelter the adults of certain species, which may even feed on particular kinds of plants when they cannot obtain blood, and may consequently find it easier to live where these plants afford them both food and shelter than elsewhere. It must also be remembered that gnats can certainly bite birds and other mammalia besides man; and that such are apt to congregate where there is much vegetation. On the whole, then, there is nothing improbable in the idea that the Freetown *Anopheles* should live outside the houses in the daytime.

(5.) *Proximity of breeding-pools to houses.*—The gorged females are, as we observed, always fertilized, and must therefore probably lay their eggs a few days later or perish. We often noticed that gravid females kept in dry test-tubes made no attempt to lay eggs unless a drop of water was put in—in which case they often deposited their eggs almost at once in the fluid. These observations suggest the conclusion that the females must return to water a few days after each

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meal of blood. As *Anopheles* larvæ were not found in vessels of water close to houses, the only inference which remains seems to be that the pregnant females must return, not to *any* water, but to some pool suitable for her offspring. If such a pool exists close to the house where she obtained her meal of blood, her journey need only be a short one; but if it be at a distance, she must fly correspondingly far—and may often be obliged to do so against the wind, or through heavy rain, or between trees.

It is therefore highly probable that, unless they can find animals and birds to feed on, *Anopheles* must seek their food in houses which are as near as possible to their breeding-pools, and also, *vice versâ*, select pools for their eggs which are as near as possible to the places where they obtain their food. In other words, they are not likely to neglect adjacent houses and pools in order to visit more distant ones. Of course many individuals must go astray—must be carried away by winds and so on; but it seems reasonable to expect that, as a rule, the breeding-pools and feeding-grounds will be as close together as possible.

Where necessity compels, however, it is probable that *Anopheles* do travel considerable distances to and fro. This must especially be the case during the dry season, when the pools must be much more rare—unless we can show that at that time the surviving adults cease to feed at all and "hibernate."

It is noteworthy that in the Tower Hill barracks we never found *Anopheles*, although there were numerous breeding-pools at a distance of only 500 yards, both to leeward and windward. The barracks are situate on a hill only 400 feet above the sea, and are surrounded by open grass, over which the insects could fly or be carried by the wind; though it should be added that occupied houses intervene between the pools and the barracks. Perhaps the insects are all attracted by these houses. The same thing was observed regarding the barracks on Mount Aureole.

The question as to the maximum distance possible between a house and a breeding-pool is an important one, but difficult to reply to. The distance will probably depend largely on local conditions, prevalent winds, screens of trees, presence of other animals, etc. We must remember that while wind may assist the insects going one way, it may equally oppose their return. On the whole it appears difficult to imagine that this maximum distance can be very great—more than half a mile, for instance; and certainly we never found *Anopheles* larvæ except in much closer proximity to houses.

Certainly gnats can visit ships lying fairly close to the shore. Dr. Wigglesworth was kind enough to give us some gnats which he had caught on board the S.S. *Fantee*, on the West Coast of Africa; and one of these was an *Anopheles*. But it must be remembered that insects blown across water are likely to travel much further than on shore—where hills, trees, and houses intervene to afford them rest and shelter.

If large numbers of *Anopheles* are found really far from human habitations, it will be not unreasonable to suppose that they can procure other besides human food. *Anopheles* are known to feed on horses and cattle, and may possibly bite other mammals, birds, and even reptiles. But it must be remembered that, in towns and villages at least, men are generally the commonest vertebrates present.

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Owing to their habit of breeding in the vessels of water which generally abound near houses, the pregnant females of *Culex* need not fly so far to find water suitable for their eggs. It is possibly owing to this fact that, to judge by their more clumsy shape, they are less adapted for prolonged flight than *Anopheles*.

(7.) *Not attracted by lamps.*—It is often thought that gnats are attracted by lamps and candles, and perish in them. They may be attracted to houses by lights burning in the windows; but we have never seen them hovering round the flames as moths and other insects do. They seem to bite less readily when there is a light in the room.

(8.) *Act of puncture.*—On applying *Anopheles* in test-tubes to the skin we observed that the insects would sometimes make puncture after puncture without drawing any blood. In such cases however, each puncture was invariably followed by the usual weal—showing that the insect always commences work by injecting some of its saliva. It therefore follows that an *Anopheles* may inject some of its saliva (possibly containing the blasts of the Hæmamœbidæ) almost instantaneously —that is, before the victim feels the irritation and drives the insect away.

It is certain that one can be bitten without knowing it—especially during sleep. Thus one often finds gorged gnats within the mosquito netting in the morning—without having been at all conscious of their bites during sleep; and it is therefore probable that those who sleep without nets may be much bitten without appreciating the fact. Even the weals often disappear in an hour or two; so that not even the marks of the punctures need necessarily remain until next day.

One of us thinks that much less irritation is caused if the insect is allowed to suck its fill, and has frequently observed the fact on his own person. This may be due to much of the irritating saliva having been sucked back during haustellation.

From several accounts it would appear that *Anopheles* hover over their victim less than *Culex* do, and consequently do not attract his attention so much by humming.

People often imagine that gnats will not bite them; but it seems to us impossible to accept such statements without sufficient experimental proof. What is more likely to be the case is that some persons do not much feel the punctures. The skin of some persons is not very sensitive; and it is moreover possible that immunity may be acquired against the irritation of the injected saliva. Thus persons who have recently arrived in the tropics are well known to suffer more than old residents. This does not necessarily mean that the latter are less frequently bitten, but, possibly, only that they have become comparatively inured to the irritation.*

17. Bionomical Questions still requiring Investigation.—The facts about gnats hitherto collected by no means exhaust the subject. We will indicate some of the more important questions which we found it impossible to deal with.

(1.) *Life in the dry season.*—Between the rainy seasons many places in the tropics are extremely arid and free from pools suitable for *Anopheles* larvæ. How then do the insects manage to continue the species from one rainy season to the other? We may assume (1) that the larvæ

* It is however possible that the body may in the course of time produce some substance offensive to the insects, just as it may produce substances offensive to micro-organisms.

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may continue to exist in such pools as do remain, the insects multiplying enormously after the first showers; or (2) that the eggs may lie dormant in mud; or (3) that the adults may "hibernate," or at least live on without feeding on blood at all, and consequently laying no eggs. We cannot pretend to give an answer to this question. In Italy it appears that the adults hibernate through the winter. One of us made an observation tending to show that the eggs can withstand desiccation for several months; but this requires confirmation. The subject appears to be of great importance in connection with the prevention of gnat-fever [*paragraph 28*].

(2.) *Other subjects.*—It is necessary also to examine how far *Anopheles* do or do not exist apart from human dwellings; whether they can breed in other collections of water than those mentioned above, as, for instance, in rain-water collected in leaves; whether they really have any connection with rank vegetation; how far they can spread from their breeding pools, how far they feed on animals, and so on.

We must again emphasize the fact that our remarks as to the bionomics of these insects are drawn only from our experiences within a limited area of Freetown [*Map II.*] in the months of August and September. We can make no statements regarding their habits, or the habits of other species of *Anopheles*, outside this limited area, or at other seasons.

18. Source of the Wilberforce *Anopheles*.—As an instance of the difficulties which may be met with, we may mention that, in spite of repeated efforts, we never succeeded in finding the source of the *A. costalis* which were so prevalent in the barracks at Wilberforce. These barracks are situated on a ridge 600 feet above sea level, and are surrounded by native houses and gardens, and by much rank vegetation. The ground slopes on either side down to the plains. Far below to the west (that is, to windward during the rains) there are a marsh and a mangrove swamp.

We searched in vain every spot likely to harbour *Anopheles* larvæ; and even examined the distant marsh and mangrove swamp without positive results. After our departure Dr. Fielding-Ould and Captain Smith, R.A.M.C., continued the search—equally in vain, except that they found larvæ in pools 1,500 yards away [*Addendum II.*].

It was often observed, however, that the *Anopheles* frequented two or three of the barracks in preference to the other buildings, and that these barracks were at the end of the block of houses. At the same time, the insects were common in the houses of the officers, who lived at that time in the village. These facts suggest that their source existed near these buildings, and not at any great distance, and that it was probably overlooked owing to the thick vegetation present. It seems very unlikely that such numbers of the insects could come from breeding pools in the marshes which lie thousands of yards away in the plain below.

The fact that so many of them were caught for examination seemed materially to affect their numbers; but we noted that newly-arrived insects invaded the barracks on one, if not more, occasions.

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V. DISCUSSIONS.

19. Questions regarding the Parasites.—Having recorded our observations in Freetown, we propose next to consider some questions of importance in connection with our subject.

The life-history of the Hæmamœbidæ as now known, and as given in the terminology previously adopted by one of us in consultation with Professor Herdman [15], is as follows [*Plates I., II., III., IV.*] :—

The youngest parasites exist as *amœbulæ* or *myxopods* within the red blood-corpuscles of the vertebrate hosts. On reaching maturity they become either *sporocytes*, or *gametocytes*.

The sporocytes are destined for the asexual propagation of the organisms within the vertebrate hosts. They give rise by division to spores; which escape into the plasma, enter fresh corpuscles, and in their turn become amœbulæ—thus continuing the species indefinitely in the blood.

The gametocytes, however, are sexual forms, male and female—the male containing a number of *microgametes*; the female, one *macrogamete*. They remain unchanged within the vertebrate hosts; but on being drawn into the stomach of a suctorial insect, perform their sexual function. The male gametocyte emits its microgametes; one of which enters a macrogamete and fertilizes it. The fertilized macrogamete is called a *zygote*.

If the suctorial insect be a species hospitable to the parasite, the zygote next escapes from the contents of the stomach, pierces the wall of the organ, and affixes itself in or on the outer coat. Here it grows largely in bulk. Its substance divides into from about eight to twelve *meres*. Each mere becomes a *blastophore* bearing a large number of filamentous *blasts* affixed to its surface by one extremity. As growth advances the blastophores disappear, leaving the capsule of the zygote packed with the blasts. The capsule now ruptures, allowing the blasts to escape into the body-cavity of the insect. From this they work their way into the insect's salivary gland; and finally pass from this gland into the blood of a new vertebrate host, in which they eventually become the amœbulæ with which the cycle commenced.

As to terminology—it will be perceived that we use the word "spore" for the asexually-produced progeny of the parasites, and the word "blast" for their sexually-produced progeny. Originally, however, neither word possesses such restricted meanings: a "spore" is a single cell capable of separating from the parent and of starting by itself a new bion or individual; while "blast" simply means a bud. Considering, however, that the recent demonstration of typical sexual functions among the Coccidiidæ and Hæmamœbidæ originates the new case of such functions (apart from simple conjugation) among unicellular animals, it may be now justifiable

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to employ these terms as indicated. We may admit that, strictly speaking, the blasts are also spores, while the spores are, in a sense, also blasts; but it will certainly be convenient in the present case to *apply* the word spore only to the asexually-produced progeny, and the word blast only to the sexually-produced progeny.

Obviously the zygote is the homologue of a fertilized ovum; and the blasts are homologues of the cells which spring from the fertilized ovum, and which construct the tissues of multicellular organisms. Only, in this case the blasts give rise, not to a cluster of cells, but to a cluster of distinct unicellular animals—by a kind of polyembryony in fact. Hence the use of the word "blast" for the progeny of the zygote appears to derive sanction from the homologous use of the same word in embryology. The word "zygote" seems to be acquiring the restricted meaning of the result of union of two similar gametes; we use it as often applied, namely, to express the result of union of any two gametes.

Of course other terminologies may be preferred by some. Professor Ray Lankester has recently been kind enough to suggest terms, which bear the weight of his authority and may be liked by many. He suggests "androspore" and "gynospore" for microgamete and macrogamete respectively—terms certainly much more definite; "gametospore" for zygote; "nomospore" for the asexually-produced spore; "oudeterospore" for any spore which is not differentiated so as to be male or female; and "gametoklasts" or "gametoblasts," or even simply "filiform young," for the blasts.

Manson was the first to interpret rightly the ascertained facts about the sexual propagation of the parasites, and his views have been adopted by other writers; but he has attempted no terminology. Grassi and Dionisi use "gamete," "microgametogene" (for microgametocyte), and zygote [19]. The term gamete had been previously applied by Schaudinn and Siedlecki to the case of some of the Coccidiidæ. The Italian observers also use the word "sporozooids" for the blasts.

Koch employs simply "spermatozoon" for microgamete [11]. The zygotes he calls "spherical bodies (Kugelförmige Gebilde)"; the meres, "secondary spheres"; and the blasts, "sickle-shaped bodies (Sickelkeime)."

The terms "sporozooid" and "sickle-shaped body" suggest somewhat doubtful analogies with the Coccidiidæ. The former term, moreover, is not very intelligible—sporozooids being, in fact, spores; while the so-called spores of the sporozoa are really often sporocysts. Compare also Mesnil [20].

The simple expressions ovum and sperm may be preferred by many to macrogamete and microgamete. Professor Harvey Gibson suggests "oosperm"—that is, the combined ovum and sperm—for zygote. The word "zooid" has been suggested in the place of blast; but zooid has the acquired meaning of a motile cell, and we do not yet know that the blasts are motile.

A biological point of some interest requires reference. Several writers seem to assume that the zygote in the gnat is the same individual organism as the female gametocyte in the vertebrate host—that it is, in short, the fertilized female parasite. This idea receives some support from the fact that the zygote contains the melanin of the gametocyte. On consideration, however, it

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seems much more likely that the life of the individual gametocytes, both male and female, ceases with the sexual function in the cavity of the insect's stomach, and that at that moment the life of a new bion—the zygote—begins. The gametocyte and the macrogamete are not identical. The former contains the latter. Perhaps this fact is best indicated by the presence of those minute spherical appendages, which have long been observed in connection with the parasites after they escape from the enclosing corpuscle, and which Professor Herdman suggests may be the homologues of *polar bodies*. Thus the female gametocyte really contains several cells, only one of which, however, reaches full development as a macrogamete. Similarly the male gametocyte also contains several cells, only one of which becomes mature and gives rise to the microgametes. Hence it is not the female gametocyte, but the progeny of the female gametocyte, which is fertilized, and this fertilized progeny constitutes a new individual, which passes its existence in the tissues of the gnat. That the macrogamete retains a portion of the tissues (containing the melanin) of its parent gametocyte is not inconsistent with biological laws; but it should be noted that, according to Mac Callum, the zygote of one avian species of the Hæmamœbidæ actually does discard the melanin of the parent gametocyte.

Hence it would seem that the Hæmamœbidæ are organisms which exhibit the phenomenon of "alternation of generations." Their full life-cycle consists of two stages—one passed principally in the vertebrate host; the other entirely in the insect host.

Mannaberg's idea that two or more amœbulæ in one corpuscle conjugate, has found support from the observations of one of us in connection with *H. relicta*. It seems possible that the gametocytes are produced by such conjugation. At any rate, it is difficult to understand what else but conjugation can happen to two or more amœbulæ in this position.

It is very noteworthy that, while Europeans who come from the West Coast of Africa suffering from gnat-fever often contain large numbers of crescents, these bodies could scarcely be found at all in Freetown. This experience tallies with the observation of one of us in very malarious districts in India [21]. It would seem that gametocytes cease to be produced, at least in large numbers, when an infection has lasted a long time—as for instance more than six months or a year. This may be explained on the supposition that the number of parasites tends to diminish as a case advances, owing to gradual production of partial individual immunity, and that it is therefore rare to find two amœbulæ in one corpuscle in old infections. Of course, in very malarious localities the majority of cases are old infections; whereas patients who resort to the Tropical Ward in Liverpool are generally comparatively recent cases [22].

We have used the taxonomical nomenclature previously suggested by one of us [15]. It is as follows (inclusive only of the parasites of men and birds):—

Family: HÆMAMŒBIDÆ, Wasielewski.

Genus I. *Hæmamœba*, Grassi and Feletti. The mature gametocytes are similar in form to the mature sporocytes before the spores have been differentiated.

Species 1: *Hæmamœba danilewskii*, Grassi and Feletti. Syn.: *Laverania danilewskii*, Grassi and Feletti, in part; *Halteridium danilewskii*, Labbé; etc. Several varieties—possibly distinct species. Parasite of pigeons, jays, crows, etc.

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Species 2 : *Hæmamœba relicta*, Grassi and Feletti. Syn. : *Hæmamœba relicta* + *H. subpræcox* + *H. subimmaculata*, Grassi and Feletti ; *Proteosoma grassii*, Labbé ; etc. Parasite of sparrows, larks, etc.

Species 3 : *Hæmamœba malariæ*, Grassi and Feletti. Syn. : *Hæmamœba laverani*, Labbé, in part. Parasite of quartan fever of man.

Species 4 : *Hæmamœba vivax*, Grassi and Feletti. Syn. : *Hæmamœba laverani*, Labbé, in part. Parasite of tertian fever of man.

Genus II. *Hæmomenas*, gen. nov. Syn. : *Laverania*, in part + *Hæmamœba*, in part, Grassi and Feletti. The gametocytes have a special form (crescentic).

Species : *Hæmomenas præcox*, Grassi and Feletti. Syn. : *Hæmamœba præcox* + *H. immaculata* + *Laverania malariæ*, Grassi and Feletti ; *Hæmamœba laverani*, Labbé, in part ; etc. Several varieties—possibly distinct species. Parasite of the irregular, remittent, pernicious or æstivo-autumnal fever of man.

The gametocytes of *H. danilewskii* are crescentic, but they are still shaped like the sporocytes (which are also crescentic)—the shape of both being simply determined by the exigencies of space within the corpuscle. There appears, then, to be no sufficient reason for separating this species from the others of genus *Hæmamœba*, in which the gametocytes and sporocytes have the same shape. On the other hand, *Hæmomenas præcox* is sharply distinguished by the gametocytes having a peculiar form of their own. Much confusion has been caused by the belief of Grassi and Feletti, who first named these organisms with precision, that the gametocytes of *H. præcox* are a separate species, akin to *H. danilewskii*—both being placed by them in a separate genus, *Laverania*. This belief they have now abandoned ; and it therefore seems necessary also to abandon the genus *Laverania*. Several observers recognise more than one species in genus *Hæmomenas*—namely, a tertian, a quotidian, and possibly an unpigmented quotidian parasite ; but, pending further research, we have accepted only one species—*H. præcox*.

The different prevalence of the three human species at different but contiguous spots (as at Wilberforce and Tower Hill), is hardly consistent with the idea that they are merely interchangeable forms of one species of parasite.

20. Cause of Occasional Failures in Direct Cultivation.—We have noted [*paragraph 9*] that a number of *Anopheles* fed in test-tubes on cases of hæmamœbiasis, and not fertilized, failed to show parasites ; while two *Anopheles* which were fed in the same manner but which were previously fertilized, did contain them. In this case the failure may be attributed to the fact that the patients contained but few parasites and were taking quinine ; but previously one of us, in association with Dr. Daniels, obtained negative results with a considerable number of *Anopheles* fed in test-tubes on two excellent cases of crescents in Calcutta. The Italian observers also note similar failures in gnats known to be hospitable to the parasites. What is the cause ?

Grassi attributes it to immunity in certain individual gnats. This can scarcely be the

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true cause, or at least the whole cause—because it sometimes happened in the Indian experiments that out of a large batch of *Culex* (according to Giles, *C. fatigans* [23]) fed on birds with *H. relicta*, every insect would become infected—or almost every insect. It is scarcely likely that the eighteen insects we refer to in paragraph 9 were all immune, while 25% of *Anopheles* of the same species caught at Wilberforce contained parasites.

The explanation which suggests itself is that something was omitted in the experiments, which is present under natural conditions, and which is essential to the cultivation of the parasites. What this is we cannot say for certain; but it is noteworthy that all the successful experiments made by one of us in India, without exception, were made with insects fed in mosquito-nets in the presence of males; while his negative experiments with various species of *Anopheles* fed on human subjects were nearly all made with females isolated in test-tubes, and therefore not fertilized.

Paragraph 16 will suggest the reason why fertilization should affect the question. The ingested blood is really required for the nutrition of the eggs. If the ova are not fertilized the blood cannot be much needed by the insect, and is possibly evacuated without some digestive process which perhaps is necessary to the vitality of the zygotes. We know that very subtle differences influence the vitality of the zygotes, because otherwise they would not perish in some species of gnats and live in others.

The point requires careful study, because until it is elucidated negative experiments cannot be entirely relied on.

The Indian experiments have shown that there is considerable variation in the number of zygotes found in gnats fed even on the same subject at the same time. This variation must depend on differences in the quantity of blood ingested by different individuals; and also possibly on some differences of quality in their digestive juices. But, at the same time, it was demonstrated that few individuals of a hospitable species entirely escape infection if fed in a natural manner.

21. Known Facts about Malaria Explained.—Caution must always be used before accepting popular theories regarding the diffusion of disease; but it is remarkable that many such ideas respecting malaria are explained and justified by the discovery that the disease is carried by *Anopheles*. We will briefly indicate the principal points.

(1.) *Malaria is endemic.*—*Anopheles* are more numerous at some spots than at others, and are entirely absent from many places.

(2.) *Swampy ground favours malaria.*—*Anopheles* breed in surface puddles.

(3.) *Level ground favours malaria.*—Pools suitable for *Anopheles* must be more common on level than on sloping ground, *e.g.*, on plains and in valleys, than on mountain sides.

(4.) *Rain favours malaria.*—*Anopheles* pools largely depend on rainfall.

(5.) *Malaria is connected with decaying rock.*—*Anopheles* may breed in hollows in rocks.

(6.) *Malaria often occurs when the soil is disturbed.*—Digging must often result in the formation of puddles suitable for *Anopheles*.

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(7.) *Embankments favour malaria.*—They also favour the formation of surface puddles.

(8.) *Towns are inimical to malaria.*—Stagnant surface puddles are not likely to be as numerous in crowded, well-drained cities, as in rural areas.

(9.) *Cultivation and surface drainage tend to remove malaria.*—They also tend to remove waste water suitable for *Anopheles* and lying on the ground.

(10.) *Malaria is not particularly connected with large bodies of water.* Gnats do not often breed in such.

(11.) *Malaria occurs on ships.*—Gnats, including *Anopheles*, visit ships.

(12.) *It is particularly dangerous to sleep in malarious places, especially at night.*—Gnats easily bite sleeping persons, and usually feed at night.

(13.) *Ground floors are most dangerous.*—Gnats seem to remain near the ground.

(14.) *Mosquito-nets protect from malaria.*—They protect also from gnats.

(15.) *Warmth favours malaria.*—It favours also gnats, and the Hæmamœbidæ within them.

In the remarkable work [1] which seems to be the first published exposition of the gnat-theory of malaria, King suggested many of these striking analogies—and indeed based his theory on them. Laveran, Manson, Bignami, and others have also independently entertained the same ideas—which may well occur to anyone who considers the subject at all. But it is now necessary to make an important correction in these views. King—and indeed other observers—seems to have thought that all gnats rise from swamps. A close student of the bionomics of gnats, however, might have almost shattered the whole argument at the outset by remarking that many of the commonest gnats do not rise from swamps at all, but from tubs, pots, etc., in the vicinity of houses; and are indeed most prevalent in the heart of large cities and in other places where there is little or no malaria. It is clear, then, that King's arguments can apply only to *certain species* of Culicidæ, namely, those which breed only in pools on the ground.

King also employs other analogies which seem to be less sound. Accepting the popular views, he considers that both malaria and gnats can be blown long distances, as to the summits of hills. It is probable that in many such cases the gnats really breed close at hand; though the observer, under the influence of the popular superstition, prefers to think that his malaria comes from the nearest marsh, although that marsh may be miles distant. King also suggests that white men are more susceptible than black men, because gnats can see the former more easily. As a matter of fact, it is always observed that gnats prefer to settle on dark surfaces; while the susceptibility of white men is more probably due to comparative absence of immunity than to more frequent infection.

22. Are other Insects besides *Anopheles* hospitable to the Human Hæmamœbidæ?—Returning to the subject just touched upon, it will be readily perceived that out of the fifteen analogies given in the last paragraph, no less than nine (the first nine) can apply only to insects which breed in pools of water on the ground. For instance, they will not apply to species of gnats which usually breed in vessels of water. Such gnats cannot be said to have a localized distribution, because they are to be found in the neighbourhood of almost every dwelling

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in the tropics. They have no particular connection with swampy ground, level ground, or decaying rock. They are not particularly encouraged by rain, by digging, or by embankments. They are not removed by cultivation or surface drainage; while they swarm in cities. Hence we may almost venture to aver that if pot-breeding gnats could carry malarial fever, almost all the phenomena of the distribution of the disease would be different from what they are known to be. That is, the disease would be most prevalent in cities; would have no particular connection with marshes and level ground, or decaying rock, or rain, excavations, or embankments; and would certainly not be removable by surface drainage. In short, it would certainly be present where it is not present, and absent where it is not absent.

It will be seen from Section IV. that these considerations would seem to exculpate a large number of species of *Culex* which frequently, if not always, breed in vessels of water.

They would also exclude most other suctorial insects, such as fleas, bugs, lice, etc.

They would not, however, exclude other suctorial insects which, like *Anopheles*, breed exclusively or almost exclusively in pools of water. It is impossible, without more study, to say how many such insects exist. Certainly some species, even of *Culex*, can often breed in pools of water.

The Indian observations with "grey mosquitoes" (*Culex pipiens* type) and "brindled mosquitoes" (*Culex tæniatus* type) all proved negative with the human parasite—with the doubtful exception of one individual. The experiments were very numerous, and the feeding was done under natural conditions in mosquito nets [*paragraph 20*].

The Italian observers record negative results with Italian *Culex*.

Koch, however, thinks that *Culex* may possibly be involved [11].

On the other hand, some nine species of *Anopheles*, existing in widely separate parts of the world, have already been incriminated.

To sum up, while it seems improbable, or indeed very improbable, that the common pot-breeding species of *Culex* are involved, it is scarcely safe as yet to exculpate the genus entirely. Observations regarding other gnats and insects which breed in puddles are still required. But on the whole it appears more probable that only gnats of the genus *Anopheles* are concerned in the propagation of human malaria.

23. Are other Vertebrates besides Man hospitable to the Human Hæmamœbidæ?—Dionisi records [24] that the two species of parasites found by him in bats are morphologically very similar to *H. præcox* and *H. malariæ*; and Koch says [11] that the parasite found by him in monkeys is like *H. vivax*. These parasites may perhaps be identical with the human species.

The parasites of birds can scarcely be communicable to man, being too dissimilar to the human ones. Exhaustive search in the blood of other mammals besides bats and monkeys is still required. In many places dogs are popularly supposed to get malarial fever.

The Indian experiments showed that *H. relicta* of sparrows can be conveyed by *C. fatigans* to crows and weaver-birds. Reasoning from analogy, then, we may suppose that the human

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parasites may infect other animals, and the converse, through *Anopheles*; and it will be noted that monkeys and bats, in which parasites like the human ones have been found, are closely allied to man. But while no strong argument can be adduced against this view, not much can be said for it. In fact the only thing which we can find in its favour is the popular notion that malarial fever can be acquired in uninhabited localities—a notion which we will presently discuss.

24. Is the Life-History of the Hæmamœbidæ fully known?—According to the known facts, malarial fever is communicated from sick to healthy persons by the bite of *Anopheles*. But a very important question remains. Is this the only way in which the disease can be propagated; or do the parasites possess some other cycle of existence, and, perhaps, some other mode of entry into man?

Nature is so full of potentialities that we can scarcely ever venture to say absolutely, at least with regard to any of the lowest forms of life, that we know all their life-history; but when one life-cycle is known, we are not justified in believing that there may or must be another, unless there are grounds for this belief. The lower forms of life, like the higher ones, cannot have an unlimited number of life-cycles. The life-cycle of the Hæmamœbidæ as already known is complex enough—are we to suppose that they possess others? If they can live freely in air and water; if they can enter man by the respiratory or digestive tracts; even if they can pass, not only from the gnat to man, but also indefinitely from gnat to gnat, they must possess different phases adapted to these modes of existence and transference, and their whole life-history must be complex indeed. They must possess not only the known phase which adapts them for life in the gnat, but other phases which adapt them for life in the soil or water—which enable them to rise in the air and pierce the epithelium of our respiratory passages, and so on. When we consider the amount of variation in structure and function which this would entail, we can scarcely be blamed for refusing to believe in other life-cycles without good evidence.

Is there any evidence which will lead us to suppose that there is or may be another cycle? *First*, is there any evidence to be drawn from our knowledge of the disease, malarial fever? *Secondly*, is there any evidence to be drawn from our knowledge regarding the parasites themselves?

It is often stated that malarial fever exists where there are no gnats; and that persons become infected without being bitten by gnats. Were cases of this kind to be substantiated, they would certainly prove the existence of other modes of infection, either by other suctorial insects, or by some quite different route. But what value can we attach to popular statements of this kind? A perusal of paragraph 16 will suggest how easy it may be for *Anopheles* to be overlooked—especially by persons who do not make an express search for them. Moreover, when we remember that a large number of cases of fever occurring anywhere are *relapses*, and that *Anopheles* may be present only at certain seasons, we must hesitate still more in accepting such statements; while the known fact that persons can be bitten without observing it discredits the other notion. We do not say that all such statements are absolutely untrue; but we are scarcely justified in accepting them until cases have been established by competent observers.

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On the other hand, it is impossible to consider the matter given in paragraph 21 without feeling that the gnat-theory suffices to explain almost all the better-established laws regarding malaria—its connection with the soil, with stagnant water, with rainfall, with rural areas, and so on. In short, there seems to be no longer *any necessity* for believing that the parasites live at all in the air or soil of infected localities. The facts on which we formerly founded our belief that they did so are now otherwise explained by the origin of *Anopheles* from surface-puddles. The facts were sound enough; our interpretation of them was wrong. Malarial fever is connected with the soil, with stagnant water, and so on, as we supposed it is; but *it is not, as we thought, the germ itself which springs from the soil—but the carrier of the germ.*

It is impossible to avoid seeing how completely this fact in the bionomics of *Anopheles* subverts the arguments in favour of the view that the pathogenetic organisms themselves have a telluric or paludal origin.

The idea that the parasites can originate in the soil, and thence pass into gnats, and from gnats to man, is opposed to all parasitological analogy. On the other hand, that they can pass alternately between men and gnats is merely an instance of a very common law among parasites.

The fact that malarial fever is communicable from the sick to the healthy has certainly been a surprising one. We thought that it is not communicable because we observed that communication does not occur outside endemic areas; while within endemic areas we attributed to an endemic poison infections which were really due to communication from the sick. By endemic (malarious) areas, we now understand simply areas which are infected by the communicating agent (*Anopheles*).

Of course the parasite itself, as well as both the hosts, must be present in an endemic area. Once present, however, there is no reason why it should not remain indefinitely so long as both the hosts remain.

So far, then, all the known facts about the prevalence of the disease seem to be easily explicable by the bionomics of the parasites and of *Anopheles*; but we now come to the consideration of the one popular theory which is not so readily explained—we mean the notion that *malarial fever may be acquired in uninhabited places.*

As a rule man lives in the society of man. Hence the vast majority of infections must take place in inhabited places—in places where previous cases of malarial fever have existed perhaps from time immemorial. Even during the most detached moments men are seldom quite solitary. Pioneers, explorers, missionaries, travellers, sportsmen, are usually accompanied by trains of servants and carriers; in order to reach uninhabited places they have to pass through native towns and villages; have to live long perhaps in native houses, and in settled camps surrounded by their followers. Ships on which malarial fever breaks out have not as a rule touched at uninhabited spots on the malarious coast, but at towns and ports where trade is carried on and may have been visited by infected coolies, or even by infected gnats, from the shore. In all such instances, cases of fresh infection may be simply explained by communication from previously infected men—at least the possibility of this can seldom be excluded. Even in the

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very rare case of complete solitaries, attacks of fever may perhaps often be attributed to relapses due to a long previous infection acquired in the haunts of men.

Travellers and sportsmen sometimes attribute their fever to having passed through a particular uninhabited but "deadly" spot. Such cases are generally questionable. On enquiry it is often found that the fever has commenced the very day, or the day after, the traveller has arrived at the place he refers to; so that the necessary phenomenon of an incubation period is wanting! A case is on record where a family of healthy natives were found living in one of the "deadliest spots" in India [25]; and we were informed that some persons who escaped from the Benin massacre, and lived several days in the reputedly deadly jungles, escaped without fever. It is certainly often possible to explain outbreaks of fever, attributed to such localities, by previous infection acquired by the suffering party in rest-houses and native villages *en route*.

If a healthy person could be carried to an uninhabited but reputedly "malarious" spot in a balloon, and should then acquire the disease, we should be forced to admit the possibility of infection in such places. Failing this, it is at least open to doubt whether autochthonous malaria does in fact exist in uninhabited localities at all.

Even assuming it does so, however, the fact would be explicable without the assistance of another life-cycle of the parasites, on the ground that *Anopheles* may possibly convey the infection from wild animals [*paragraph 23*]. For instance, both monkeys and bats are often found in large numbers in forests reputed to be malarious.

Failing even this, if it can be shown that autochthonous malaria does exist in uninhabited places, the fact would be more readily explained on the hypothesis that the Hæmamœbidæ can pass from gnat to gnat, than on any other. And this leads to the second question given above. Is there any evidence to be drawn from our knowledge regarding the parasites themselves in favour of the view that they possess another life-cycle?

The Indian observations showed that in many of the zygotes of *H. relicta* found in *C. fatigans*, certain large, black, sausage-shaped bodies occurred. These were provisionally called by one of us "black spores." They occurred not only in the zygotes, but in other parts of the gnat; facts which he at first explained on the assumption that they are produced within the zygotes, are liberated on the rupture of these, and are then distributed by the insect's circulation throughout its tissues in a manner similar to the way in which the blasts are distributed. Later, however, he observed in gnats which were not infected with Hæmamœbidæ at all, bodies which were very similar to these black spores, but which showed evidences of fission in the manner of the fission fungi, and indeed of growth entirely independent of the Hæmamœbidæ. Consequently he at once modified his statements about these bodies [21], and suggested that, though he could not say for certain what they are, they may be some parasitic organisms in gnats which have the power also of invading the zygotes of the Hæmamœbidæ. He at first thought that they might be meant for infecting the larvæ of gnats, and indeed made some negative experiments in this connection, but later abandoned all hypothesis on the subject pending further researches. Since then the "black spores" have been found by other observers, who also have failed in elucidating their nature. In Freetown we noted bodies very like them in a few *Anopheles*; but

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these bodies were never seen within the zygotes, while they often occurred, mixed with what looked like segments of a fungus, within the sheath of certain muscle-fibres (*e.g.*, of the stomach), and indeed appeared to have no relation at all with the Hæmamœbidæ.

If these bodies are indeed forms of the parasites, they will certainly suggest another life-cycle. In this case they will probably infect larvæ, for the purpose of continuing the species from gnat to gnat. The probability of one of them ever reaching man's digestive or respiratory tracts must be so remote that we can scarcely imagine that they are provided for this purpose. In the meantime it remains to be proved that they have any connection with the parasites at all.

It should also be noted that many full-grown zygotes do not contain blasts,—a fact which suggests that they *may* be set apart for some other purpose. At the same time they may merely be zygotes which for some reason have not been able to ripen as early as the rest.

The method of diffusion of the disease by inoculation through the proboscis of gnats is so perfect a one that, now we are acquainted with it, it seems difficult to imagine the existence of any other—such, for instance, as the clumsy methods which in our ignorance we formerly imputed to nature. In the transference of the parasites from man to man by gnats, there is an economy which would not have existed had nature sown the organisms broadcast through the soil or air, on the chance of one of them occasionally infecting a human being.

To sum up, then—there appears at present to be no strong evidence, based on our knowledge either of the disease or of the parasites, in favour of the view that the latter possess any other life-cycle besides the one which is already known. On the other hand, the fact that malarial fever is communicated from sick to healthy persons by *Anopheles* seems sufficient to explain all the well-established laws regarding the prevalence and diffusion of the disease.

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VI. PREVENTION.

25. Measures Indicated.—It is a well-known fact that malaria has been often eradicated from certain localities by cultivation and drainage of the soil. Hence we are justified in saying that the possibility of prevention has been demonstrated in some cases by experience. But cultivation and drainage are generally large and costly measures, and are often impossible. We propose now to examine whether the new observations regarding the propagation of the disease can suggest any cheaper, more precise, or more effective means of prevention.

Since the disease is certainly conveyed by *Anopheles*, it is obvious—whether this be the only mode of propagation or not—that measures taken against these insects in any locality must assuredly be at least beneficial, even if they do not result in the entire extirpation of the malady in that place.

King long ago pointed out [1] that if malarial fever be produced by gnats, prevention of the disease will consist in precautions against their bites by mosquito-nettings, window screens, and inunctions of the skin; and in measures for the exclusion or destruction of the insects, such as screens of trees, smoke, fires and lights (in which he supposed they destroy themselves), and the draining of swamps and pools. Similar ideas have occurred independently to other observers who have considered the gnat-theory. Nuttall gives [12] a summary of measures against gnats recommended by various writers—such as draining or dumping the pools, or flushing them; or agitating the water by wheels turned by wind-mills; or the introduction of small fish; or by the introduction of gnat-eating birds and dragon flies; or by the use of fires, "lamp-traps," and so on, of inunctions to the skin, and of various "culicicides," such as kerosene oil; or by the plantation of water-absorbing trees. Celli and Casagrandi have recently reconsidered the subject, and have recorded a number of valuable experiments with various culicicides [26].

It will be observed that these measures can be resolved into two classes, namely :-

(1.) Precautions against the bites of gnats.

(2.) Measures for reducing their numbers.

Of course, if malarial fever be communicated only by the bite of gnats, as there is now every reason to suppose [*paragraph 24*], these measures will include the entire prophylaxis against the disease. If there be also some other method of propagation, other methods of prevention—the nature of which we cannot now indicate—will also be called for.

Note also that we refer only to the prevention of *infection*, not to the prevention of the *recurrences* of fever, which often occur in a patient years after the primary infection, and which are not connected with the original infective causes at all.

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26. Precautions against the Bites of Gnats.—We shall content ourselves with recording a few practical remarks in this connection.

(1.) Numerous substances have been vaunted as being efficient "*culicifuges*," such as oil of lavender, eucalyptus, kerosene oil, etc. [12]. It is scarcely advisable to trust to any of them until their value has been demonstrated by experiment. Even if an effective culicifuge exists, it is hardly to be expected that many persons in malarious localities will use it constantly.

(2.) *Lights* in a bedroom tend to prevent gnats from biting—not by attracting them, as many suppose ; but more probably by alarming them. They seem to prefer darkness for feeding. Many species of gnats bite voraciously during the daytime, even in verandahs and under trees. These are generally gnats of the *C. tæniatus* type.

(3.) In India, natives certainly seem more prone to infection than Europeans. This may be partly attributed to their wearing less *clothing* and not generally sleeping in mosquito-nets. It should be observed, however, that natives of India (and, we believe, negroes) generally sleep with a sheet drawn over their heads, for the express purpose of keeping off gnats ; and the method is undoubtedly partially effective.

(4.) Some writers imagine that the *darkness of the skin* of the coloured races is a preventive against gnats. As a matter of fact, it will be generally observed that gnats settle on dark surfaces, and are probably *attracted* by dark skins, instinct telling them that they are likely to find their food there.

(5.) In India it is universally recognised that *fans* and *punkahs* keep away gnats to a large extent. Thus many persons dispense with nets and sleep only under punkahs—a questionable practice in the presence of *Anopheles*, because, unless the punkah swings rapidly just over the body, gnats are not much deterred by it.

(6.) *Mosquito-nets* must be entirely free from holes, because gnats find their way through the smallest aperture. They should also have a doubling or valance just above the surface of the bed, in order to protect the hands, feet, and knees of the sleeper when thrust against the net during sleep. If the weather is hot the net should not be dispensed with, but a punkah may be employed *over it*. The top of the net should be made of gauze. Tent-shaped nets are hot and close because they fall in folds. A rectangular net, tightly stretched inside a wooden framework, and carefully tucked under the mattress, is much better. The net should never be allowed to fall to the floor. Unless care is taken while getting into bed, gnats frequently enter with the occupant. Mosquito-nets are often used in so stupid a manner that, instead of excluding gnats, they *include* them—gnats which have previously entered being allowed to remain within the net for days.

(7.) *Screens* to windows are little employed. They would probably be very effective indeed. They should be made of fine wire with a fairly large mesh, and should be fixed immovably if possible, because gnats find their way in and out of windows at all times of the day. They are often employed in America.

(8.) Some persons have such a dislike to being bitten that they are constantly on the watch for "mosquitoes," and drive them away or kill them whenever possible. Such certainly escape much more than those who are indifferent to the insects, or those who think they are immune against them.

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While it is never possible entirely to avoid being bitten, careful persons can certainly avoid being bitten to a very large extent by the use of some of the measures indicated above; and evidently the less one is bitten the smaller are the chances of infection. Indeed it is probable that the general neglect of these precautions by a community largely enhances its sick-rate. Thus in India the natives seldom employ either the punkahs or the mosquito-nets which are so generally used by the well-to-do whites; and are certainly much more subject to fever. The poorer Europeans, also, frequently neglect these necessities; and also appear to suffer more than the richer people. We were much struck by the fact that in Sierra Leone both nets and punkahs were seldom employed—or if nets were used, they were not used effectively; and we have heard that they are similarly neglected in many other places on the West Coast. It is not at all unlikely that this fact will partly account for the fever-rate on the West Coast being so largely in excess of what it is in India.

That this is not an exaggeration will be more readily perceived by those who possess actual experience of life in different tropical localities. In some, where nets and punkahs are not generally used, our lives at the mercy of these insects—it is impossible to sleep, eat, read, or even in some cases to stand still, without being bitten by them. In others, such for instance as the large Indian cities and cantonments, where punkahs are kept going all day and nets are jealously used during sleep, one often lives for several days without suffering a single bite. The risk of being bitten—and consequently, in malarious localities, of infection—must therefore be greatly diminished by these precautions. Assuming that the risk is diminished to one-fourth—and this is scarcely too much—we may calculate that the fever-rate will be correspondingly reduced by three-quarters. Prophylactic measures which promise anything like so much are certainly not to be despised.

Nets and punkahs, then, should always be employed in malarious countries by persons who can afford them.

Screens of wire-gauze to the windows seem to be especially indicated in public buildings such as barracks, hospitals, jails, and asylums. In such buildings there are usually large wards in which a number of persons sleep together. Here—as for instance in the Wilberforce barracks [*paragraphs 7, 9*]—the *Anopheles*, if they are present, simply carry the infection uncontrolled from one to the other of the inmates, until finally a large number become infected. Screens would limit both the ingress of the insects, and also their egress for the purpose of laying their eggs. Thus few insects would gain admission, while those that do would probably soon perish [*paragraph 16*].

Lastly, medical men must always remember that patients with gametocytes in their blood are *infective* where *Anopheles* exist, and must be jealously protected from bites in the interests of other occupants of the same or neighbouring houses.

It will be observed, however, that precautions against the bites of gnats, while feasible to intelligent and well-to-do persons, are scarcely likely to be employed by the mass of the population, at least in malarious areas outside Europe and America. Other measures are required for the prevention of gnat-fever on a large scale.

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27. Operations for Reducing the Numbers of *Anopheles*.—Such operations will be divided into :—

(1.) Destruction of adults or larvæ.

(2.) Measures to prevent the insects breeding.

Where the larvæ cannot be found—as at Wilberforce—destruction of the adults can be resorted to. The gorged females, that is, the insects which are particularly liable to be dangerous, can often be killed while seated asleep in the daytime on the walls of a house. The same thing may be done on *ships*; and it is quite possible that many infections may be prevented in this manner. Native servants become very expert at the work. But, of course, such a measure will not be possible on a large scale.

The most vulnerable point in the history of gnats is when they are larvæ ; they can then be destroyed wholesale. In the case of larvæ in vessels, it suffices simply to pour out the water on the ground ; but it is more difficult to deal with larvæ in pools, drains, cisterns, wells, streams, drinking fountains, and rice-fields, etc. Even here, however, very simple measures may often suffice.

Thus small puddles can be *brushed out* with a broom, the larvæ dying on desiccation if the operation be done in dry weather. We judged that in Freetown 80 % of the puddles could be treated in this manner with little labour.

Other pools can often be *evacuated*, or *filled up with earth* by means of a few strokes of the spade. The former, however, may be impossible in perfectly level country.

Where these simple measures are impracticable recourse may be had to "*culicicides*." The most popular of these is *kerosene oil* (paraffin). We found that this can be most easily applied by means of a rag fixed on a stick. In this manner a number of puddles can be "painted" in a few minutes at the cost of but little oil ; but enough oil must be used to make a fairly permanent film. Aaron states that for five dollars sufficient oil can be purchased to make five applications to 100 acres of water [12]. Strachan recommends *olive oil* mixed with a very small proportion of *turpentine*, especially for cisterns of drinking water [27]. Nuttall quotes writers as saying that *copperas*, and even *rusty iron*, are culicicides ; certainly larvæ are not commonly found in iron vessels, except when water runs into them—as from a tap. Numerous other culicicides are suggested by the work of Celli and Casagrandi [26].

It is obvious that by these means we can destroy a large number of larvæ at any time ; and it is even possible that by repeatedly dealing with every pool in a given locality we may ultimately be able to exterminate, or almost exterminate, the insects in that locality. But there is one serious difficulty. Such operations carried out on a large scale will require constant care, involving a great deal of trouble and some expense ; while untrustworthy agents will be very likely to neglect their work. This will especially be the case if the *Anopheles* pools are very numerous. It will therefore be generally preferable to deal with the insects by *preventing them breeding* altogether.

Two ways of doing this suggest themselves—

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(1.) The whole of the area of operations must be carefully dealt with by draining away or filling up every collection of water which is found to harbour *Anopheles* larvæ at any time.

(2.) Some cheap culicicide which will have the effect of rendering the pools permanently uninhabitable for the larvæ must be employed.

The first will be an engineering work, the details of which need not be considered by us. Its cost will obviously depend on the number of pools existing in the locality of operations, and on the natural difficulties in the way of draining them or filling them with earth.

The second measure will depend on the discovery of the substance which will have the effect required. It must be some cheap solid substance which kills larvæ without injuring higher animals, and which, when sprinkled on depressions in the ground, will render the pools which form there uninhabitable for the larvæ for a long time—say for months or longer. Such a substance has yet to be found by proper experiments; but we may suggest *tar* and *lime* as being possibly suitable.

When placed in water, tar constantly gives off a film like that produced by kerosene oil, but more permanent. Judging from Dr. Fielding-Ould's experiments [*Addendum II.*], it would seem to destroy larvæ in a more effective manner than oil does; but it remains to be seen how long its effects will last.

Lime is suggested by a paper by Grellet [28], of which we have seen only a review. Dr. Grellet gives instances to show that this substance is inimical to malaria; and cites particularly the example of Châtillon-sur-Loing, where malaria is said to have disappeared as the result of an extensive application of lime to the soil for agricultural purposes. As it could scarcely have acted otherwise than by rendering surface pools uninhabitable for *Anopheles* larvæ, we may surmise that lime may be a substance such as we require.

The fact that *Anopheles* do not exist in many localities where suitable pools must be present, suggests that the soil there contains constituents which are inimical to the larvæ; and it is at least probable that something like the required culicicide actually exists. If it be found, we may possess a very practicable mode of eradicating the insects from areas which we elect for operations.

In conclusion, there can be little doubt that we may often be able largely to reduce the number of *Anopheles* in some localities by these measures. If we may assume—as it seems we may—that the malariousness of a locality depends *ceteris paribus* on the number of *Anopheles* present in it, this would mean that these measures may often enable us largely to improve the health of certain places.

28. Under what Conditions do Operations against *Anopheles* promise to be most Successful?—It will, however, be at once apparent that the practicability of employing these measures in any given locality must depend on two factors, namely, (1) the number of *Anopheles* pools present, and (2) the feasibility of attacking the pools.

Judging from the careful study of the question which we made in Freetown, we

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unanimously came to the conclusion that these operations, if scrupulously prosecuted, promised to be successful in that town. The pools—at least during the time when we were there, the height of the rainy season—were not very numerous; and could easily be attacked, at but little cost, by any of the measures indicated above. That is, we judged that either if the larvæ were persistently destroyed, or if the pools were carefully obliterated, the insects might be very largely reduced, if not almost exterminated, in the area studied by us [*paragraph 13, Map II.*]. It is of course impossible to speak with absolute certainty on the point until the experiment has actually been tried; but from all indications we thought this conclusion was a reasonable one.

But even if the operations ultimately prove to be successful in Freetown, it does not follow that they will be equally successful elsewhere. The conditions obtaining in Freetown do not obtain everywhere; and we have already pointed out that, owing to the hilly nature of Freetown, the pools there are both limited in number and are easy to drain [*paragraph 13*]. On the other hand, the large rainfall in Freetown (163 inches) is favourable to the formation and permanence of puddles in that place.

Judging from our observations, the number of *Anopheles* puddles in any given locality at any one time is likely to depend upon a number of factors, namely, (1) amount and continuity of rainfall, (2) humidity of the atmosphere, (3) height of the subsoil water, (4) flatness of the ground, (5) porosity of the soil, (6) presence of small fish in surface puddles, (7) use of wells and of pools for agriculture, (8) temperature; and also probably on (9) the chemical nature of the soil, and (10) presence of some vegetable food necessary to the larvæ or even to the adults. Hence we may expect much variation in the number of *Anopheles* pools in various localities.

In some tropical countries, as in parts of Assam for instance, vast level areas are almost under water during the rains. In such places the larvæ may abound everywhere; unless it happens—and the point requires study—that small fish are too plentiful for them. Here it will be impossible to drain or fill up the pools.

Again, in Lagos, Strachan [27] and Fielding-Ould [*Addendum II.*] report that the pools are extremely numerous, while the ground is so flat that it will be difficult to drain them.

In Freetown the pools are much less numerous than in Lagos, and we think it possible to attack them with success.

In Accra, Fielding-Ould did not succeed in finding a single *Anopheles* pool when he was there.

In Secunderabad, in India, only one pool was detected in a considerable area examined by one of us—though others might have been overlooked.

In the Bolan Pass, malaria certainly exists, though the country approximates to a desert. In such places pools must be very isolated.

In Travancore, James reports [29] that the larvæ are found in pools used for obtaining drinking-water, and also in the submerged plots of ground in which rice is grown (paddy-fields).

Possibly the larvæ may breed in *wells*—which are often very numerous in tropical cities.*

* Since this was written, Cornwall has described finding *Anopheles* larvæ in unused wells in Madras city [30].

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Lastly, in many places where there is much forest or undergrowth, it may be impossible to indicate the pools at all.

Even in localities where the pools are sufficiently few, it may be difficult to deal with them. This will be especially the case with wells, pools of drinking-water, small streams, rice-fields, irrigation pools, and pools on water-logged ground.

On the other hand, operations may be very much facilitated if we can succeed in finding a cheap substance, such as was alluded to in the preceding paragraph, which will prevent the insects breeding in the pools. Suppose, for instance, that a ton of such a substance will suffice to keep a square mile of land free from *Anopheles* for a whole rainy season, we may hope to eradicate malaria from our principal towns at but little cost.

Again, as suggested in paragraph 17, if *Anopheles* live from one rainy season to another only by continuing to breed in the few pools which remain during the dry season, we may then be able to attack them with comparatively little trouble at that season. This is an indication which requires following up. It is difficult to understand how the insects tide over the dry season in places in which almost every inch of soil is then subjected to a heat sufficient, one would think, to destroy even the eggs. Unless the adults "hibernate," we may suppose that the larvæ still live in wells, or gardens, or in pools in the bed of watercourses which have nearly dried up. If this be the case, operations against the insects may be much facilitated.

On reviewing these observations, we shall see that—

(1.) Operations against *Anopheles* are least likely to be effectual in level, water-logged localities, and in places where the insects breed in pools which cannot easily be found, or cannot easily be treated.

(2.) Operations will probably be easier in country which is not quite level, or where the rainfall is not great.

(3.) They promise to be very easy in extremely dry places.

Lastly, it goes without saying that we can scarcely ever expect to deal with *Anopheles* in large rural areas. On the other hand, we may reasonably hope to reduce them, if not to exterminate them, in the principal centres of population and civilization—that is, in just the places where prevention of malaria would be most useful—provided always that we make intelligent and persistent efforts to do so.

29. Recommendations.—The method of dealing with malaria by operating against *Anopheles* would seem to have this advantage over the old method by drainage of the soil—it promises to be much cheaper. Whereas by the old method we were obliged to drain the whole of an infected area—often at great cost—we shall now be called upon to drain, or otherwise deal with, only those spots which are the source from which the insects (and, by hypothesis, the disease) emanate.

The fact that drainage has often actually banished malaria now only suggests that drainage has often actually banished *Anopheles*. By reducing this long-known method to one of greater precision, we may now reasonably hope to obtain the same effect with greater ease.

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Financial considerations have frequently prohibited the employment of the old method; they can scarcely prohibit the employment of the new one—at least in many localities.

Although the new method has not yet been tested by actual experiment, all the scientific indications support the view that it will be a valid one.

The existence of the disease is in many localities such a serious source of expense, not to mention loss of trade, prosperity and life, that the small sums required for the prosecution of the new method cannot justifiably be withheld, even though it is still in the experimental stage.

Hence we feel justified in recommending that operations against *Anopheles* be included among the sanitary measures of local governments and municipalities.

We also recommend that further investigations regarding the prevention of malarial fever be prosecuted with the energy which our national obligations demand.

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VII. REMARKS.

30. Miscellaneous Remarks.—The following notes may be of interest.

(1.) *Destruction of gnats, generally.*—It is a most astonishing fact that though gnats constitute a serious pest in nearly all tropical towns, one seldom hears of any efforts being made to control their numbers. Even Europeans appear to be generally quite ignorant of their source, and often allow them to breed in large numbers in tubs and flower-pots just outside their windows; and then complain of their presence and attribute it to the "locality." It would be a benefit to the community if medical men would exert their influence with local municipalities in favour of some action against these insects— not only *Anopheles*, but *Culex* as well. A single intelligent native agent, whose services could generally be obtained for one or two pounds a month, would be able to do a great deal of good in many towns, simply by going from house to house and emptying the vessels of stagnant water, or by treating them with culicicides, or by showing the occupants what to do. Sanitary inspectors might also be instructed to attend to the matter. The policy of indifference adopted at present is ridiculous.

(2.) *Houses of Europeans in the Tropics.*—We have already referred to the fact that punkahs and mosquito-nets are not as generally used in Sierra Leone as in India. In the latter country Englishmen seem to have learnt by long experience how best to live in the tropics. Not only do they employ these comforts wherever possible, but their houses are as a rule specially adapted for tropical life—they are generally commodious, well-built, and surrounded by a large open area or "compound." Undoubtedly this must assist in preserving the occupants from a great deal of fever. Gnats do not like airy, well-lighted rooms; while, if there is a large compound, infection cannot be as easily carried from adjacent houses. Moreover, in India there is generally a separate European quarter, which is as a rule built on the most elevated site present. In Freetown none of these precautions have been adopted. In addition to the neglect of punkahs and mosquito-nets, the houses are small, crowded together, mixed with the houses of the townspeople, and built in the lowest part of the town. *Anopheles* easily live in them, can bring in the infection from numerous neighbouring dwellings, and can feed uncontrolled on the occupants; while they find numerous pools suitable for them in the ditches by the side of the streets.

On the ridge behind Kortright Hill there is a large plateau over 1000 feet above sea-level, and capable of holding the houses of all the Europeans in the colony.

Serious attention ought to be given to this question of the houses of Europeans in the tropics. If *employés* are sent at all to dangerous climates, it is the manifest duty of their employers —whether these employers be the Government or private persons—to see that they are housed in

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a manner most likely to preserve their health. If the nation wishes to maintain colonies in intensely malarious localities, the least it can do is to protect its servants as much as possible from the disease.

(3.) *Surface-drainage of Freetown.*—This is undoubtedly bad as a rule. The substitution of simple masonry gutters for the existing roadside ditches would probably have a considerable effect on the malaria. In some spots, however, it will be necessary to avert drainage from the hills.

(4.) *Disposal of night-soil.*—As already mentioned, a system of pit-latrines is in use in Freetown. Not only does there seem to be little dysentery or enteric fever present in the city, but the disgusting odours so frequent in Indian towns (where removal systems are adopted) are comparatively infrequent. In short, it is open to question whether this pit-system—which we have compared to a septic-tank system—is not preferable, if it can be adopted, to the ordinary Indian interception method. A pipe water-supply must of course exist at the same time ; and the subsoil water must be low.

(5.) *Filariæ in* ANOPHELES COSTALIS.—In many of the *Anopheles* caught in the Wilberforce Barracks we found *Filariæ*. All the stages described by Manson, up to the final motile stage, were present. We add photographs of an earlier and a later stage—the former from a specimen considerably distorted by the preservative (formalin).

7.—*Filaria* in *Anopheles costalis*. Young stage.

8.—*Filaria* in *Anopheles costalis*. Older stage.

It is impossible to doubt that these parasites, like the Hæmamœbidæ in the same insects, were derived from the soldiers ; but unfortunately we were unable to obtain the blood of the latter at night for examination. One of us had previously observed *F. nocturna* in the tissues of *Anopheles* fed on a patient containing the parasites [5].

(6.) *Tumba-fly and Tsetse-fly.*—We found these insects in Freetown. Accounts of them will probably be published elsewhere.

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(7.) Towards the end of our stay in Freetown, one of us was attacked with fever : *H. præcox* being at once found in his blood. From the first there was no rigor. The fever was continuous, but disappeared (together with the parasites) on the fifth day, as the result of treatment with quinine. The drug was continued for six weeks, and no relapse has occurred.

(8.) *Distribution of* ANOPHELES COSTALIS.—It is always difficult, without elaborate study of perfect specimens, to come to sound conclusions respecting the species of gnats. So far, however, as we could judge from specimens obtained from various parts of the West Coast, *Anopheles costalis* appears to have a wide distribution there. See, for instance, Strachan [27] and Fielding-Ould [*Addendum II.*]. We may even conjecture—pending more certain information—that it is the principal agent of the deadly West Coast fever.

(9.) *Use of the microscope for clinical purposes.*—We beg earnestly to recommend that Laveran's discovery, which has now been made for twenty years, be used in medical practice in malarious localities. The microscope is called for, not only for diagnosis and treatment, but in order to obtain exact information regarding the nature of the various fevers prevalent in warm countries—fevers which often cannot be differentiated by the symptoms alone. For example, we do not yet know the nature of black-water fever—a point which would probably have been decided long ago if medical men had more generally adopted microscopical methods in their practice.

(10.) In conclusion, it should be strongly emphasized that many substances which have not the power actually of killing *Anopheles* larvæ may yet be capable of rendering depressions in the ground uninhabitable for them for long periods. Common salt may be effective ; but the range of substances for experiment in this connection is very large. It is to be hoped that such experiments will soon be made.

FINIS.

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ADDENDUM I.

Description of Two Species of ANOPHELES *from West Africa.*

By Major G. M. Giles, M.B., F.R.C.S., I.M.S.

Owing to the sudden departure of Mr. Austen, late of the Liverpool Malaria Expedition, for the seat of war, I have been asked to draw up a formal description of the two species of *Anopheles* brought by the party from the West Coast of Africa. I should however mention that, having run over the specimens with Mr. Austen, I am indebted to him for many of the points specified, so that the description might almost be said to be a joint production.

We are agreed in considering one of the two species as undoubtedly identical with *Anopheles costalis*, Loew, originally described by him from Caffraria, but which now appears to have a wide distribution over, at any rate, a large proportion of the tropical and subtropical African littoral. The other species does not appear to have been previously described, and, at Mr. Austen's suggestion, has been named *Anopheles funestus sp. n.*

The following are the descriptions of the two species in question :—

Anopheles costalis, Loew.—Wings with the costa interrupted by patches of darker and lighter colouration, but not generally dark ; the costa has the basal third dark with two minute interruptions followed by three other dark spots, the first of which is the largest, separated by smaller yellowish interruptions ; portions of the other veins are black-scaled, but the lighter tinted scales preponderate. Abdomen not distinctly banded, but with the hind border of the segments rather darker, especially in the male. Tarsi with minute rings, mainly apical, but involving also the base of the next joint.

Description from Loew, *Berlin Ent. Zeits*, 1866, *p.* 55.

" ♀ Pale tinted, with the palpi black with white rings ; wings with uniformly black costal spots. Length of the body, 2 lines ; of the wings, $2^1/_{12}$ — $2^1/_6$ lines.

Clay coloured. The two first joints of the antennæ yellow ; remaining joints brownish. Palpi black, with a white ring on each of their joints. Thorax with a bright brownish longitudinal stripe on either side, and a distinct brownish line in the middle. Pleuræ striped and speckled with pale brown. The hairs on the thorax, scutellem, and abdomen entirely light yellowish. Legs yellowish brown ; the femora yellowish at the base ; all the outermost points of the knees and tibiæ of a yellowish colouration. Wings limpid, with pale yellowish, almost white-haired veins, with here and there patches of black hairs, so as to produce a characteristic marking of the wing ; of these spots the most striking are four placed on the anterior border of the wing and not extending beyond the first longitudinal vein, and forming elongated black spots which alternate with clearer portions of the wing-border ; the spots on the remaining part of the wing are not so distinct, because, owing to the veins being placed further apart, they nowhere approach each other sufficiently close to admit of their black portions combining to form a noticeable spot. Habitat—Caffraria, South Africa."

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In the examples collected on the West Coast, with the exception of the wings, the insect is a dark brownish grey rather than clay coloured. The palpi of the ♀ have the apex broadly white, and there are, in addition, two narrow white bands on the articulations: further, their scaly covering is rougher than in *An. funestus*. The legs are dark brown, somewhat speckled with yellow, especially beneath, but show nothing of the nature of a band, except on the tarsi. In the fore legs, these have the first three joints with apical bands, which involve somewhat the contiguous bases of the next joints: in the middle legs the first three; and in the hind, the first four joints have purely apical, narrow yellowish bands. The wings are lighter than in *An. funestus*, but have a larger proportion of dark scales than in *An. rossii*, *mihi*, or, to judge from his figures, than Ficalbi's *pseudopictus* and *superpictus*. The ♂ has the terminal joint of the palpi with a dense tuft of hairs, which are brownish yellow internally and blackish externally: the only other ornament being a very minute ring on the articulation between the second and third joints.

Mr. Austen further makes the following note :—Although this species much resembles *An. pictus*, Loew (described from two females from the coast of Asia Minor, opposite the island of Rhodes) in having the front femora thickened towards the base, I think it is undoubtedly distinct. In the first place, it is much smaller (only $2\frac{1}{4}$ instead of 3 German lines). Then the two last joints of the palpi have an adornment of yellowish white scales instead of being brown; and the wings have four dark blotches on the costal margin in place of three, and all are separate, whereas in Loew's species the first and second patches are joined together on the costa itself. Lastly, the legs differ, the tarsi being banded in *costalis*.

This species forms one of a group of closely allied species, including *An. pictus*, Loew, *An. superpictus*, Grassi, *An. rossii*, *mihi*, *An. vanus*, Walker, and some others, which agree in having the wings with the costal margin adorned with alternate dark and light spots, while the wing as a whole is not dark tinted. When closely examined, however, the details of the adornment of the wings, as well as that of the palpi and other appendages, afford sufficient points of constant difference to assure us that they are specifically distinct.

The other (and new) species is much more darkly tinted, the white interruptions on the costa and other veins being so much smaller than the dark portions that it is fairer to call their wings black, with white spots rather than the reverse. In this respect it forms a link between the paler forms and the densely black-scaled wings of two species, also new, but as yet undescribed, which were brought back from India by Major Ross, and are now in the British Museum.

Anopheles funestus, sp. n.—Wings with the costa marked by interrupted darker and lighter colouration, the dark portions preponderating; on the actual costa there are five interruptions, the two basal being connected by dark scales on the auxillary vein; there are also white areas over the transverse veins, the stem of the posterior fork-cell, and the bases of the 5th and 6th longitudinal veins. Abdomen unbanded, black. Tarsi uniformly black.

♀ General colouration black, with but little adornment. Head black, with a crest of scattered white scales; eyes with a minute white margin; proboscis black, a little paler at the apex; antennæ black, with scanty whitish verticils; palpi black, very smooth, with the apex and two narrow bands on the articulations white. Thorax black, clothed with white scales over the greater part of the dorsum. Legs black, the only relief being a scarcely perceptible paler knee-ring. Wings ornamented as above described; the anterior fork-cell long, parallel-sided, with a short stem; the posterior, much shorter, wider, and wedge-shaped, with a longer stem; supernumerary and middle transverse veins of fair length, in one line, the posterior, shorter and more than twice its length internal to it; the scales of the internal fringe with minute white interruptions opposite the junctions of the longitudinal veins with the margin. Halteres with the knob black and the stem rather lighter. Abdomen black, glabrous, with very scattered white hairs.

In the ♂ there is no obvious banding of the palpi, but the apex of the last joint is grey, followed by a narrow black ring, and then by an even narrower pale ring, the rest of the appendage being of the same funereal tint as the rest of the body. The antennæ are black with dense black verticils, which, however, show a certain paler lustre in certain lights. The abdomen is black. The wings, though they resemble those of the ♀ closely in ornamentation, differ somewhat in venation,

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the anterior fork-cell being twice as long as the posterior, and its stem much the shorter, though both stems are rather long, while the posterior is very short, and but little wider than the anterior.

Length, excluding the proboscis, 2.6 mm.

Habitat.—Freetown, West Coast of Africa.

Owing to the absence of ornamentation, the description of this species is necessarily brief, but it will, I trust, suffice to distinguish it from any neighbouring species.

G. M. GILES, M.B., F.R.C.S., MAJOR I.M.S.

ADDENDUM II.

Observations at Freetown, Accra, and Lagos.
By R. Fielding-Ould, M.A., M.B.

I. SIERRA LEONE.

In accordance with instructions I joined Major Ross at Sierra Leone in September last, and during the remainder of his stay there co-operated with him in his researches; and later, when he returned to England, I continued the work of the expedition in Freetown.

The habitat and "breeding puddles" of the *Anopheles* which had been observed infesting the Wilberforce barracks we had been unable to discover, and I determined to make further and more rigorous search through the surrounding country than had been possible hitherto. In this I received the valuable assistance of Captain Smith, R.A.M.C.; but, notwithstanding the most careful explorations, we were unable to find any *Anopheles*-bearing puddles nearer to the barracks than 1,500 yards. Those we found were more or less permanent pools in the crevices of rocks below Signal Hill; and some others were found in Murray Town. I am inclined to think that these puddles are the puddles that supply the mosquitoes which infest the barracks. It has been observed that the *Anopheles* are only to be found in the barracks intermittently—that is to say, a swarm may be present for two or three days, and then for a week no mosquitoes are to be seen. This fact, and the impossibility of finding any puddles nearer than a mile, I venture to explain by the hypothesis that the wind is an important factor in the matter. The prevailing wind blows over the puddles that I have mentioned in the direction of the barracks, and by its means, when favourable, the mosquitoes may be able to travel a long distance—quite contrary to their ordinary habits.

In support of this view it may be mentioned that many facts are on record which seem to indicate that the poison may be carried to some distance by winds. Again, it has been noticed that of the two banks of a stream in a malarious district, that towards which the prevailing winds blow is often the most affected.

During the remainder of my stay in Freetown I was kept supplied by consignments of mosquitoes from the barracks, and I also obtained some from the houses of natives known to be suffering from fever. Dissection of these gave substantially the same results obtained by Major Ross. I include with these notes some drawings, made on the spot, of microscopical preparations, which show various phases of the malarial parasite in the gnat (Plate IV.)

Out of 29 *Anopheles* examined by me, six, or 18 per cent., gave definite parasites; while 17 *Culex* gave in every case negative results.

I made experiments on the puddles at Freetown with both tar and kerosene as culicicides. Both these proved effectual as larva-destroyers, but the former is, in my opinion, likely to prove the

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more successful ultimately. In the same street many puddles bearing larvæ were treated—some with kerosene and some with tar. After 24 hours all were free from larvæ. After a further interval the puddles were again examined; with the result that all the puddles treated with tar were still free from larvæ, while many of those treated with kerosene contained larvæ. This result is due to the greater evanescence of the kerosene film.

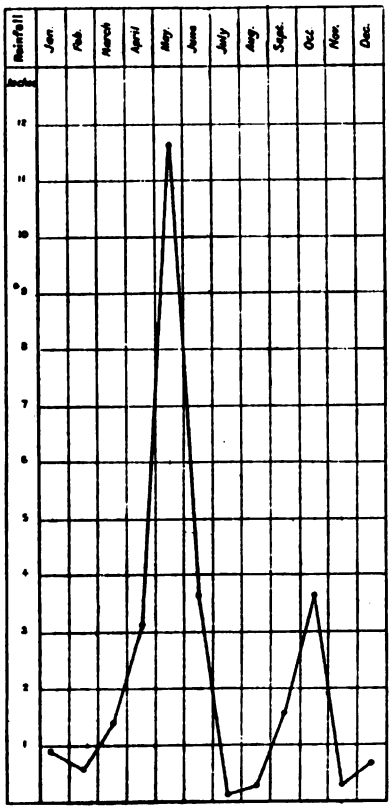
II. ACCRA.

On October 18th I landed at Accra, and after being very kindly received by the Governor of the Gold Coast, who spontaneously offered me all the assistance in his power, I was fortunate enough to meet Dr. Chalmers, who kindly offered me quarters, and for whose hospitality and assistance in my work I cannot too warmly express my gratitude.

Accra, a straggling town consisting roughly of four parts—native, commercial, official, and Christiansborg—(*vide* Map III.) is situated on a perfectly flat plateau on the coast, about 25 feet above sea level. From the level of the town to the sea-shore stretch broken and crumbling rocks; and on the other side, northward of the town, the country is absolutely flat (save for a slight depression here and there) for 26 miles, until the Aburi Hills are reached.

During my stay at Accra I was unable to find any puddles, and consequently *Anopheles*, notwithstanding a rigorous search throughout the entire district. To those who know the conditions under which *Anopheles* were found at Sierra Leone this will not be surprising, for the conditions at Accra are totally different; the rainfall never exceeds 27 inches per annum, as compared with 170 inches at Sierra Leone. Again, at Sierra Leone the geological formation is volcanic rock, whereas Accra is built on sand and gravel; consequently the small rainfall is very rapidly absorbed by the porous ground. There are no trees, and therefore there is no shade.

RAINFALL AT ACCRA, 1897



I include here a chart showing the curve of the rainfall at Accra.

It has been found that the number of fever cases is greatest during the second quarter of the year, that is to say, just before, during, and just after the period of greatest rainfall (*vide* chart). Another rise in the number of cases occurs in the last quarter; when again it will be noticed that the rainfall increases. At this time too the "*Harmattan*" blows, and there is a great fall in the temperature at nightfall. The increased liability to chill at this time no doubt, to some extent, explains the increase in the number of fever cases. I may say that during 1899 the rainfall has been somewhat less than usual.

Not only was I unable to find any specimens of *Anopheles* in Accra, but Dr. Chalmers, an enthusiastic entomologist, also had not seen any during the three months prior to my arrival. Other kinds of mosquitoes were present without limit; and I seized the opportunity to examine as many of the *Culex* species as possible. Fifty-two specimens I dissected, but in none did I find zygotes. Before deciding that *Anopheles* is never found at Accra, we must wait to see if they are present when the rains are at their height, that is to say, in May or June.

These being the chief facts which I obtained as regards the mosquitoes of Accra, one would

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naturally expect to find that malarial infection was comparatively a rare event there. And this is precisely what we do find. All my enquiries from local medical men and colonial surgeons led me to believe that there had been no case of "original infection" for two and a half months before I arrived. During this time there had of course been "recurrent cases," though these had not been numerous—only thirteen among Europeans. These, I venture to say, are important points; but I do not wish to lay too much stress on them, for I fully realize that it would be rash to draw too rigid conclusions from observations carried on over so limited a time; but it is, in conjunction with facts observed elsewhere, at least significant of the influence of the mosquito in the propagation of malaria.

It should be noted in this connection that all authorities, in each of the three Colonies that I had the opportunity of visiting, agreed that 1899 had been an exceptionally healthy year; so that probably the number of fever cases was below the average.

Thanks to the efforts of the present Governor—Sir Frederick Hodgeson—the official population is now better housed: spacious and well-ventilated bungalows have been provided, and these have been removed nearly a mile eastward, so that the native town with its squalor and overcrowding is no longer the menace that it was (*vide* Map III.). On the other hand, many of the habitations of the commercial population are badly built and badly ventilated; some are still in close proximity to the native huts, and some to that part of the sea-shore which I shall refer to again as practically a public latrine. To improve the sanitary condition of the native town much has recently been done in some districts. A fire in 1896 burnt down many of the huts in one part, and afforded an opportunity of opening up the maze of squalor that previously existed. Broad streets were laid down, a partial system of drainage started, a stinking pool in the market place filled up and better houses built—with the result that disease of all kinds in this district diminished. Several districts remain in all their primitiveness, and similar treatment could not fail to bring about a marked improvement. But the Government, though alive to its responsibilities in this matter, are handicapped by a want of money for the purpose, and also not a little by restrictions imposed at home by a mistaken and sentimental regard for what are called "native rights." Already so much has been done with good results that, in my opinion, advanced with the greatest diffidence, Accra is not the death-trap its reputation would warrant one to believe. This reputation has been built up partly by the many cases of sickness imported from the hinterland; and to get a right conception of the general health of Accra it is necessary to draw a distinct line between the seat of government and the northern territories of the colony. I do not mean to say that it will ever become a health resort, nor do I think it would be wise to extend (as has been by some suggested, including the late Governor, Sir William Maxwell) the length of the "tour" of service. The climate, quite apart from any specific disease which may there exist, has a definite reducing and depressing effect on European constitutions. However healthy a man may be on his arrival on the Gold Coast, sooner or later he becomes anæmic or dyspeptic, and often his nervous system is so affected that a condition of extreme irritability is induced; insomnia often follows, and he becomes totally unfit for work.

It should not be overlooked that the difficulty—often impossibility—of procuring fresh meat and vegetables is after a time a serious tax on any constitution, however strong. There is a widespread belief that alcoholism is rampant on the West Coast; I may say here that, though I had good opportunities of judging, I did not find it so in any of the three Colonies I visited.

That part of Accra known as the "native town" (*vide* Map III.) needs further consideration here, in order to make it clear that what I have already said may not seem exaggerated, and that it is in fact a standing menace to the health of the community at large.

In this part of the town there are no streets. Winding alleys, unpaved, and so narrow that two persons cannot stand abreast, do duty for streets. These alleys have interminable ramifications, and form so complex a maze that it was found impossible by the surveying authorities to chart them. Numberless naked children disport themselves in these gutters, and many mangy dogs are seen wandering about under no control. In addition to these, sheep and goats of a more or less unhealthy appearance roam the byeways. Filth of all sorts is found lying broadcast in the alleys; stinking garbage, decaying vegetables,

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etc.; and, to crown all, the natives wash themselves openly in the puddles they have made for the purpose. The children for the most part use these byeways as latrines. Mosquitoes abound, and the odour is often frightful. The huts are made of mud roofed in with leaves. They are overcrowded to an appalling extent—8 or 10 persons often occupying a hut 9 or 10 feet square. Scattered here and there through this district are groups of uninhabited, roofless and often ruined huts. These are used by the neighbouring families as places in which to discharge their refuse, and also as latrines. Every now and then one comes across a butt or other receptacle filled with stinking water, infested with mosquitoes, and infected with bacteria. The latter I was only able to examine microscopically. The former were all of the genus *Culex* —no *Anopheles* were found. A complete absence of any system of drainage completes what to a European eye is nothing but a noisome and a pestilential district. The danger of such neighbours to the white population is obvious, and some of the commercial community, as I have said, live very close indeed to those parts of the town. This danger is, I think, increased by the fact that the prevailing wind sweeps over and through these native dens before reaching the houses of the white inhabitants. Public latrines have been indeed provided by the Government on the sea-shore, but I am of opinion that these are themselves not wholly without danger. Some are flushed by the sea; but on October 20 two were entirely dry—and that on a day when the tide was of quite average height. Much of the open sea-shore is used as a public latrine too; and it is easy to imagine in such a climate the condition of affairs thus brought about. Any infective material deposited here is liable also to be carried by the prevailing wind straight to the European quarters. The problem of drainage and general sanitation is no doubt a very difficult one to solve in a place which is so flat, and where there is no water supply (the inhabitants are entirely dependent on a scanty rainfall). But I venture to think much benefit would result from the running of broad streets through the congested districts of the native population, and the destruction of uninhabited houses. An attempt is made by the police to keep the streets in a clean and healthy condition; but it is impossible to exercise anything but very incomplete supervision over these unlighted rabbit-warrens. All wandering dogs and other animals not properly looked after should be destroyed, for that there is a possibility of their carrying diseases I do not think anyone is inclined to deny. I am disposed to think that the sea latrines should be done away with, and earth-to-earth land latrines substituted. These latter are used with complete success in some parts of Lagos, though there too there are some latrines open to the lagoons.

The suburb of Christiansborg shown on the map has no such plague spots as I have described in the native town of Accra. Here there are broad streets, well kept, and for the most part clean; the houses are not crowded together, and there is a fairly complete system of drainage. The drains are open, wide, and made of cement. Between this suburb and Accra there are a few acres devoted to surface pools, which the natives enclose to catch the rain for various domestic uses; and on these pools they are entirely dependent for their water supply. Some contained mosquitoes (all *Culex*, no *Anopheles*), various weeds and algæ; but were sweet and clean for the most part.

It may be surprising that so near Accra a suburb with the above characteristics should exist; but it is easily explained: Christiansborg Castle was at one time the Governor's residence, and Christiansborg itself the seat of government. At this time some thousands of pounds must have been spent to produce the good result I have sketched above. The present Governor is doing everything in his power to improve sanitation in Accra, and though, as I have said, he is hampered in various ways, slowly but surely an improved state of things is showing itself.

The authorities and West Coast medical men generally are now fully awake to the fact that all has not yet been done that may be done to improve sanitation, and in the next few years I anticipate a definite improvement in this respect, and also a greater activity in scientific medical research. At present any research is carried on under almost disheartening difficulties. Instruments rust, microscopes and other lenses become cloudy (even the cover glasses and slides which I took out with me became useless), and bacteriological research is quite impossible under present conditions.

Now, however, I think I may say a new epoch is about to begin in the scientific study of diseases prevalent on the West Coast. The Government of the Gold Coast has sanctioned a preliminary

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expenditure of £500 for the formation of a medical research laboratory at Accra, and before I left I had the pleasure of seeing the building almost ready and fit to receive its scientific equipment. Much, too, might be done, I venture to suggest, throughout the Colony in this direction. At present no facilities—not even microscopes—are provided for the assistant or Colonial surgeons on duty in the hinterland. When one considers that by the microscope we are alone able to diagnose malaria with certainty, this complete absence of proper instruments is not only appalling, but incomprehensible. In this connection I may say that there is reason to believe that many cases are wrongly attributed to the malaria parasite, and earnestly treated with quinine. Were it feasible, though for certain political reasons it may not be possible, I think better results would accrue if each assistant Colonial surgeon had a definite district assigned to him with a permanent headquarters, where he might, with a small outfit of scientific apparatus (at least the microscope, which he is at present without), do much good work in the interests of tropical medicine. The Colonial surgeons are at present so continuously travelling (often unavoidably, no doubt), that to expect any scientific work would be ridiculous. But I do not think that a central research laboratory at Accra—receiving films of blood, pathological specimens, etc., for examination—will entirely meet the case, especially in a climate where morbid specimens so rapidly change their character. There is already a well-appointed and well-managed hospital at Accra, open for the reception of white and black alike ; and here, too, improvements are being made.

There is no doubt that at Accra the greatest desideratum is a proper water-supply. Up to the present time, though borings in every direction have repeatedly been made, no water fit for drinking purposes has as yet been discovered. Rain-water can alone be obtained, and must be stored in tanks for long periods—during which time it runs great risk of contamination, though every care be taken. A scheme is on foot to bring water from the Aburi hills, 26 miles away, at the cost of over £100,000. But considering the great expense of this, and the great hindrance to all forms of business caused by the short term of service imposed by the climate, it is surprising that only during the last year has the possibility of moving the whole community to Aburi been mooted.

Parasites were not found in any out of 47 *Culex* examined by me at Accra.

III. LAGOS.

I proceeded to Lagos, and arrived there on October 27. The Chief Medical Officer of the Colony (Dr. Henry Strachan) offered me quarters ; and for the great hospitality he showed me during the whole of my stay I wish here to express my sincere appreciation and gratitude. Lagos is the largest town I visited. It has roughly 75,000 inhabitants, of which about 150-200 are Europeans. Any estimate of the population is necessarily only approximate, because the taking of the census is the signal for a general exodus of the natives for the bush. The town itself is built on an island surrounded by lagoons (*vide* Map IV.). The highest point is 19 feet above the level of the water, while, on the other hand, several parts are actually below sea-level. The island consists geologically of sand deposited on the top of mangrove swamps ; and borings reveal the existence of alternate strata of sand and decaying vegetable matter. The swamps (shaded on the map) are seen to almost entirely surround the island. These evil-smelling quagmires consist largely of mangrove trees and black mud—the latter has a peculiarly offensive odour, due chiefly, I think, to the evolution of sulphuretted hydrogen gas. Under the microscope I found this mud to consist chiefly of sand and decaying vegetable matter : many protozoa also were present. The Europeans live almost entirely in one limited part of the town, their quarters being stretched out along the edge of the south-western lagoon (*vide* Map IV.). They are therefore, it will be observed, surrounded on two sides by swamp and lagoon, and on the other two sides by native habitations. These latter I need not describe, as they bear a general resemblance to those existing at Accra.

The geological formation of Lagos being such as I have described, it is not surprising that puddles suitable for the breeding of *Anopheles* are plentiful. The island may almost be said to be one immense puddle ; for the ground everywhere lends itself to the formation of small collections of water and mud on

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the occasion of the slightest rainfall. In this respect the contrast presented between Lagos and Accra cannot fail to be noticed. *Anopheles* I found to be so widely distributed that it was impossible for me to make any distinction in favour of one part of the town as compared with another. In every native hut—in all European quarters—in Government House—even in the hospital—I never failed to find some specimens. My search for parasites was not equally successful; for, although I dissected 37 specimens, I was only in one able to satisfy myself of the presence of zygotes.*

During my stay at Lagos there was very little fever; only two cases were admitted into hospital, and no out-patients presented themselves for treatment. The blood of both these patients I examined; but no parasites were present, though the examination was made on more than one occasion. This did not however surprise me, for both were mild cases, and had been taking large doses of quinine for six days before admission. *Anopheles* caught in the wards, and others "fed" on these same two cases, gave also negative results.

The single specimen in which I found zygotes was caught in a native (Hausa) hut; but I was unable to trace the cases, and so failed to obtain other specimens. I also, at Lagos, dissected 17 specimens of *Culex;* but, as at Accra, these invariably gave negative results. The problem of how best to deal with the *Anopheles* and their breeding-places is a peculiarly difficult one at Lagos. The peculiarities of the soil, and the extreme flatness of the island, render it impossible, in my opinion, for drainage to be an effectual solution. For similar reasons, and also on account of the universal prevalence of the mosquitoes—*Anopheles*—it does not seem to me likely that the application of kerosene or tar to the puddles will be altogether a successful method. In some few places an attempt has been made to drain marshy ground into the lagoons, and occasionally this has no doubt done good; but, taking the town as whole, this is not feasible, and some other method of extermination must be devised. The Government, if I may say so, have certainly been acting in the right direction by filling up some of the more aggressive mangrove swamps with sand; but this is necessarily a long and tedious business, and at the best, only a portion of the evil can be treated in this way.

In these swamps, as also at Sierra Leone, I looked for *Anopheles*, but in neither place did this particular genus seem to frequent them. Both drainage, as far as it is possible, and the application of kerosene would no doubt do something to improve matters; but until some further measures can be devised, the people of Lagos must rely chiefly on the general and less direct means that were recommended at Sierra Leone, *e.g.*, the intelligent use of mosquito-nets and blinds, etc.—of both of which there is at present a surprising absence.

The "Rest-House," which is used as temporary quarters for Government officials, I found swarming with *Anopheles;* and I was able to obtain particulars of several cases of malarial infection occurring there. Before my arrival, and indeed before the mosquito theory had been brought prominently forward, several officials dated their fever from nights spent at this "Rest-House" among hosts of what everyone recognised as a peculiarly vicious variety of mosquito. I am now referring to several well-authenticated cases, the details of which Dr. Strachan is, I believe, about to publish. From a consideration of these cases one is led to the conclusion that malaria has a definite incubation period of from 7 to 21 days.

I include here a chart which shows the rainfall, sub-soil water, and fever curves in Lagos for twelve months. It will be seen that these curves are as nearly as possible coincident, the maximum number of fever cases occurring a little later than the point of highest sub-soil water. It is impossible to suppose that this is a mere casual coincidence, and that the two curves have not a definite relation to one another. The bearing of these observations on the validity of the mosquito theory is obvious, for we know that the *Anopheles* are most prevalent when the sub-soil water is highest.

It has often been observed in many parts of the world that the upturnings of earth, and excavations generally, were accompanied by an increase of malaria: it is certain that the turning up of soil will aggravate the manifestations in districts where malaria is permanently endemic. This has also

* This can be attributed to the gnats not having become previously infected from patients.

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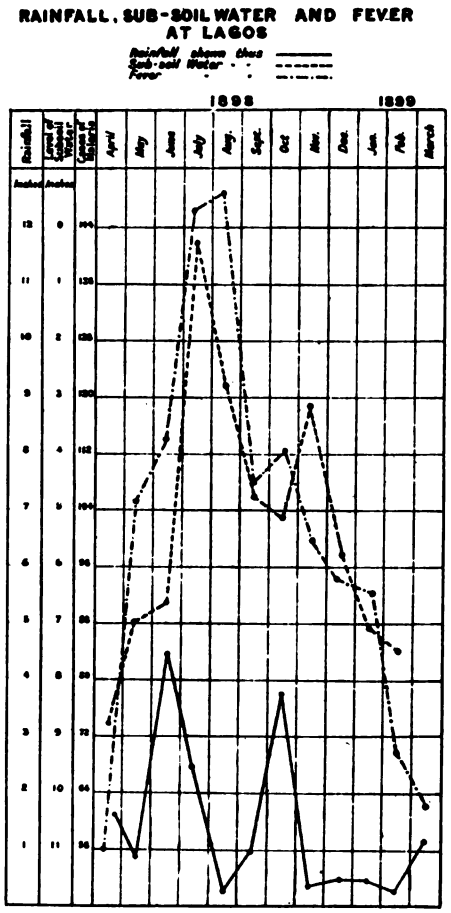
been observed in West Africa, and especially by railway engineers—who perhaps suffer more from fever than any other section of the white population. I was anxious to see if this could be explained on the ground that the upturning of earth caused an increase of *Anopheles* puddles. When, therefore, the Governor, Sir William Macgregor, M.D., K.C.M.G., invited me to go by special train up the Lagos Railway from Abutemetta to Aro, I eagerly seized the opportunity. I found that the railway track was entirely a made track, and that to provide the soil for embankments, etc., many excavated pits had been made. In some places, for a mile or more these pits remained gaping at intervals of about twenty yards. In all that I examined there were puddles of varying depth and size, and without exception these puddles contained *Anopheles* larvæ. This is, to my mind, a point of great interest and importance, and may entirely explain why in West Africa, at any rate, railway engineers and officials are peculiarly and pre-eminently exposed to malarial infection.

Throughout the West Coast malaria is ever before men's eyes as an inevitable evil which all must suffer at some time or another; and the result is that any rise of temperature is immediately diagnosed as malaria, and rigorously treated with quinine. I saw at least one case in which a lady suffering from a typical attack of pneumonia (temp. 104° F.; dyspnœa, complete evidence of consolidation, etc.) was diagnosed as malaria, was treated with quinine, and was going to the bad. Fortunately a medical man, comparatively new to the coast, with a mind open and not befogged by coast tradition, was called in, and a correct diagnosis made: the lady recovered with a typical crisis.



This is a glaring instance of the tendency on the coast to diagnose any rise of temperature, be it heat insolation, pleurisy, rheumatism, or even constipation, as malaria. The absence of microscopes, and the apparent want of belief in the advantage of microscopical investigation, is responsible to a great extent for this state of affairs; but traditional ideas born before the discoveries of Laveran still hold sway, and cannot wholly be exculpated.

It is noteworthy that black-water fever occurs at all periods of the year; and, as far as I can judge, its curve of incidence bears no relation whatever to any of the three curves on the chart. Black-water fever occurs chiefly among two classes of the European community, viz.—

(*a*) Roman Catholic priests and nuns.

(*b*) German commercial community.

Investigation shows that the connecting link between these two classes, and the fact that distinguishes them from other classes, is that they are the most overworked, the worst fed, and, as a general rule, obtain the least leave to Europe. Some never leave Lagos.

I was informed that black-water fever is becoming more frequent in West Africa, but that its virulence is distinctly diminishing. As in the case of malaria, microscopical examinations of the blood in black-water fever is the exception rather than the rule, but I never met any medical man in West Africa who had been able to demonstrate blood-parasites in these cases. From a consideration of these facts I am inclined to think that black-water fever will one day prove to be a fever *sui generis*, and wholly unrelated to the malarial parasite.

In Lagos, again, as in the Gold Coast, I venture to say that the disinterested activity of the English Schools of Tropical Medicine is bearing good fruit. Before I left I heard that 15 microscopes had been

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ordered for the use of the surgeons in the Colonial service. A laboratory for research is also being built, and cannot fail to do good work. In the hinterland, too, facilities for microscopical investigation are being provided.

There remains the water supply of Lagos to be mentioned. The absence of a proper water supply, as in Accra, must necessarily bear its share of responsibility for much of the unhealthiness that obtains. In Lagos, again, the people are dependent on the rainfall alone for their supply of water.

The rainfall in Lagos amounts on an average to 70 inches per annum, and must be stored in tanks for use during long periods. The risk of contamination is great, and until lately no great effort was made to keep the tanks in good order. Recently, in consequence of the recommendations of the C.M.O., a better state of things has been inaugurated, and every effort is now being made to keep the tanks clean and free from vegetable growth and mosquito larvæ. Public latrines are provided by the Government. Some are open to the lagoons; others, the most sanitary I think, are earth latrines; and it would be well if more of the latter were provided, and those open to the lagoons closed.

I should have mentioned that there are in places shallow surface wells from which the *natives* obtain most of their water: into many of them the sub-soil water drains, and their use can only be viewed with suspicion.

The hinterland is in many parts healthy, many districts affording high lands and good water, where white men could live in perfect security. It was suggested by the late governor, Sir William Macallum, that the seat of government should be removed some twelve miles up the railway from Abutemetta. This should present no insuperable difficulties, and would be an untold benefit to the Government officials, who form at present a large proportion of the white population of Lagos.

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DESCRIPTION OF THE PLATES.

NOTE.—Plates I., II., and III. consist of photographs taken mostly from unstained preparations preserved in formalin. Formalin accentuates the outline of the zygotes; on the other hand, a small amount of detail has been lost in the collotype process. Hence the result is that the photographs show the parasites almost exactly as they are seen in fresh preparations of the tissues of the gnat, except that the granules of melanin do not come out with sufficient clearness in all the figures. None of the photographs have been in any way retouched by hand.

PLATE I.

Figure 1 (× 500).—Very small zygotes of *Hæmamœba relicta* attached to stomach wall of *Culex fatigans*. The melanin has become enlarged by the formalin. Coloured.

Figure 2 (× 500).—Very small zygotes of *H. relicta* attached to stomach wall of C. fatigans. Unstained. The melanin is of the natural size.

Figure 3 (× 500).—Very small zygotes of *H. vivax* attached to stomach wall of *Anopheles costalis*. Unstained. Melanin scarcely appreciable in the collotype.

Figure 4 (× 500).—Very small zygotes of H. malariæ in *A. funestus*. Unstained.

Figure 5 (× 500).—Small zygotes of *Hæmomenas præcox* in *A. costalis*. Unstained.

Figure 6 (× 500).—Small zygotes of *H. malariæ* in *A. costalis*. Unstained.

PLATE II.

Figure 7 (× 500).—Larger zygotes of *H. relicta* in *C. fatigans*. One well shown protruding into the body cavity of the host. Unstained.

Figure 8 (× 500).—Still larger zygotes of *H. vivax* in A. costalis, showing great delicacy of the outline. Unstained.

Figure 9 (× 500).—Medium sized zygotes of one of the human species in *A. costalis*. The focal plane is taken through one of the blastophores (in the middle of the zygote). The blasts are already nearly mature. Unstained.

Figure 10 (× 500).—A zygote of *H. relicta* about two-thirds of the full size, protruding into body cavity, and containing blasts which are already nearly mature. Unstained.

Figure 11 (× 500).—A full-sized zygote of *H. relicta* full of mature blasts, many of which are seen to be packed side by side (near the lower margin). Unstained.

Figure 12 (× about 60).—Stomach of *C. fatigans* with mature zygotes of *H. relicta*, as seen by a low power. Coloured.

PLATE III.

Figure 13 (× 500).—Mature zygote of *H. relicta* full of blasts; and also capsule of another (to the left) containing "black spores." Unstained.

Figure 14 (× about 400).—Blasts and "black spores" of *H. relicta* in *C. fatigans*, apparently ejected together from the capsule of a zygote. Unstained. The "black spores" do not seem to be mature.

Figure 15 (× 400).—Blasts of *H. relicta* lying free in the juices of the thorax of *C. fatigans*. Unstained. Many lie in perspective.

Figure 16 (× 500).—Four blasts of *H. relicta* in juices of C. fatigans, dried and stained.

Figure 17 (× 500).—Blasts of *H. relicta*, dried but not stained.

Figure 18 (× about 400).—Blasts of one of the human Hæmamœbidæ in the salivary gland of *A. costalis*. Unstained. The blasts are closely packed within the salivary cells, and also lie outside the cells, within the capsule.

PLATE IV.

Drawings, by Dr. Fielding-Ould, of the Hæmamœbidæ found by him in *Anopheles* in Sierra Leone.

Figures 1-9.—Zygotes—apparently of *H. vivax*.

Figure 10.—A zygote discharging blasts.

Figure 11.—Individual blasts.

PLATE V.

Drawings of *Anopheles costalis* and *Anopheles funestus*. Made at the British Museum.

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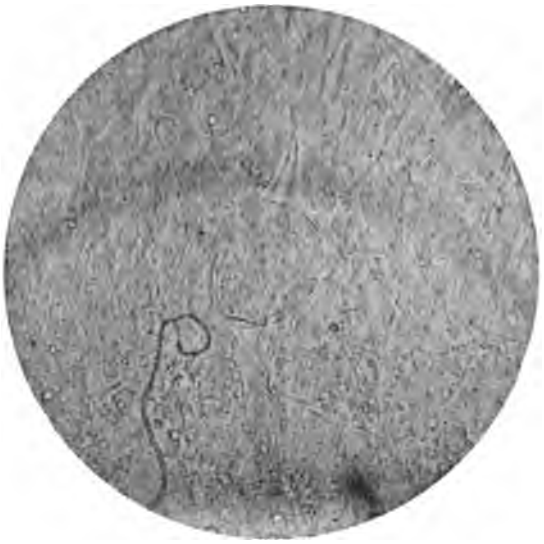

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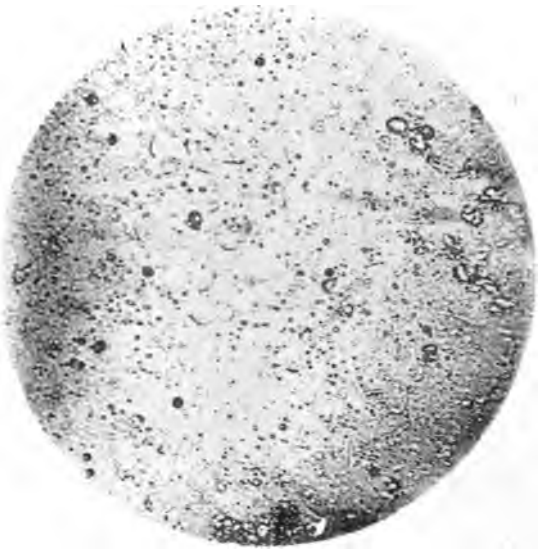

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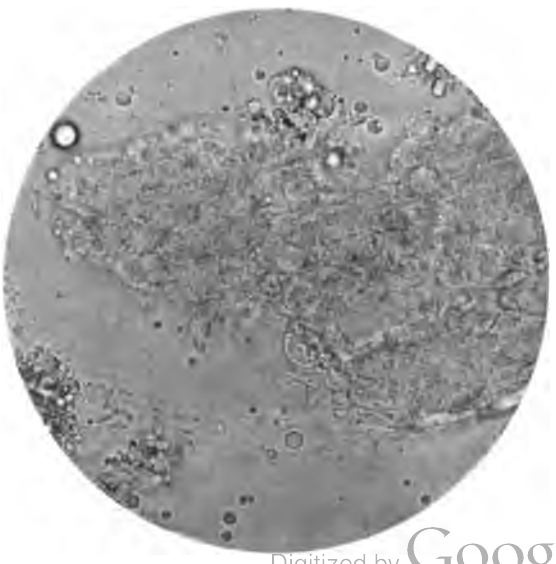

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PLATE IV.

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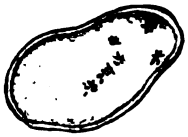

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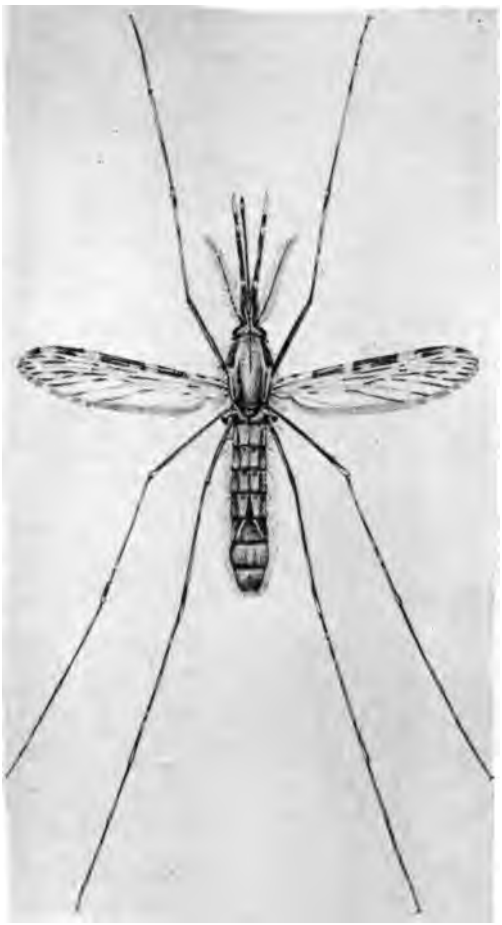

Anopheles costalis.

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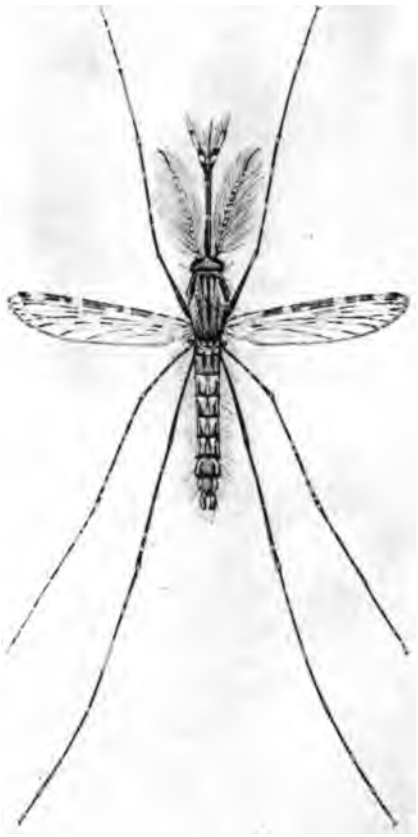

Anopheles costalis

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Anopheles funestus.

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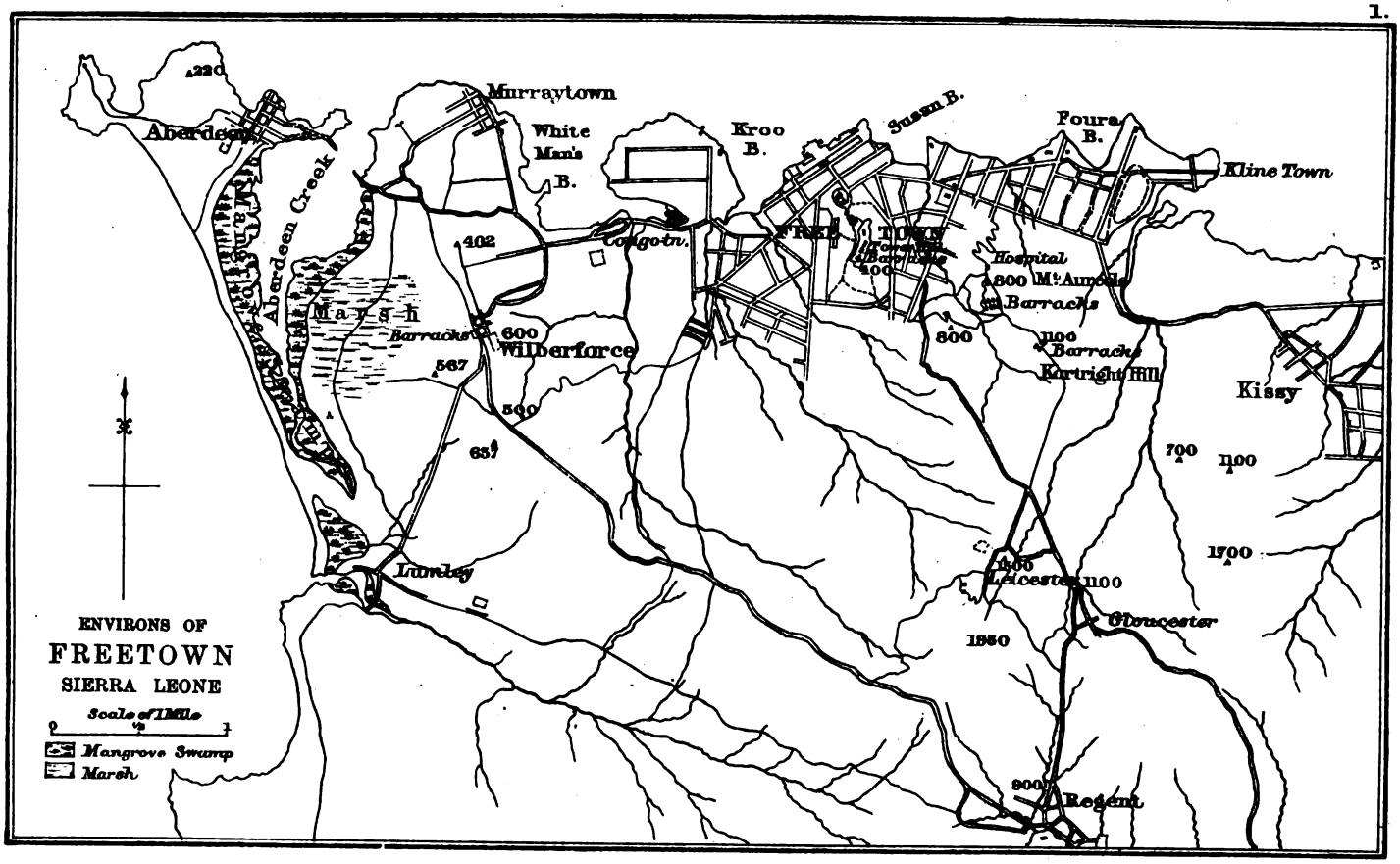

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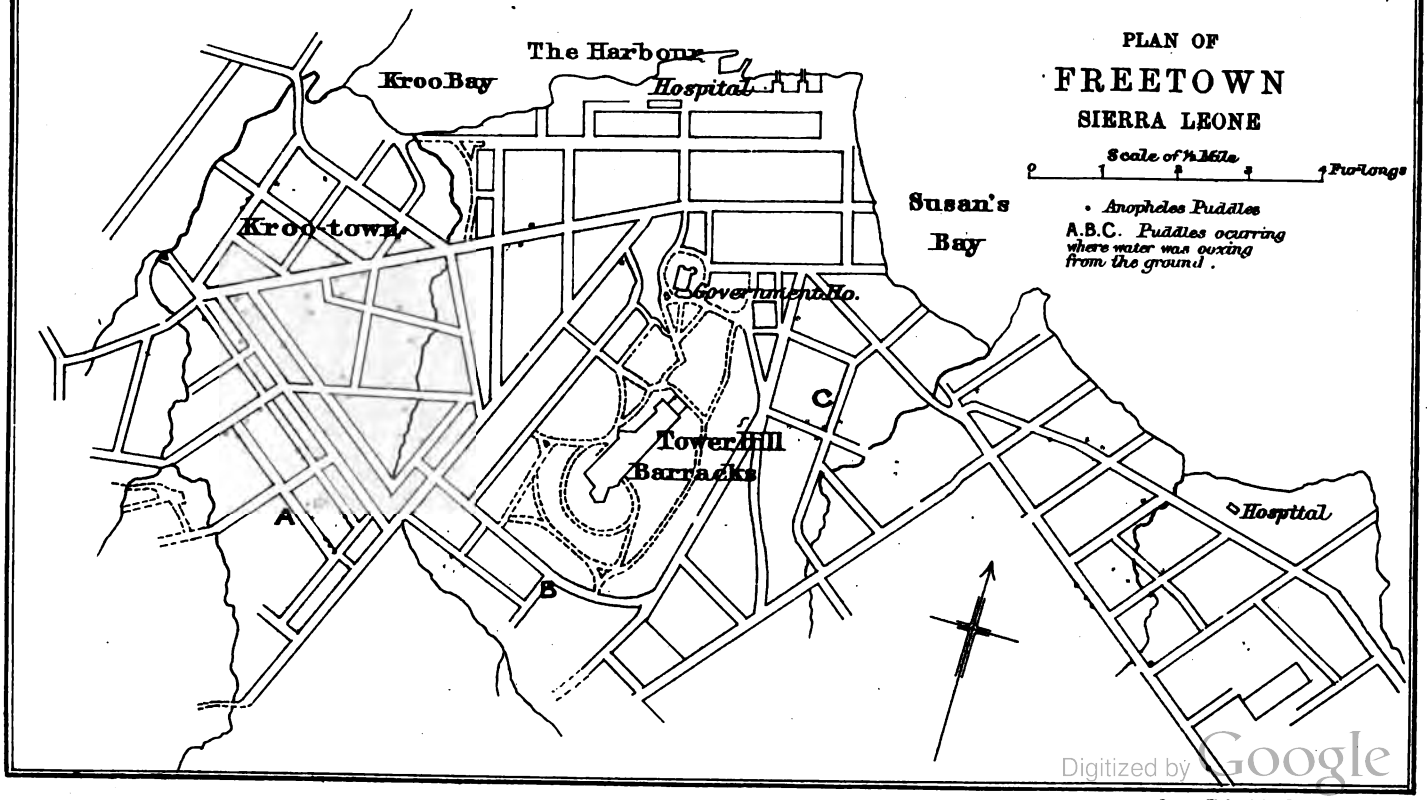

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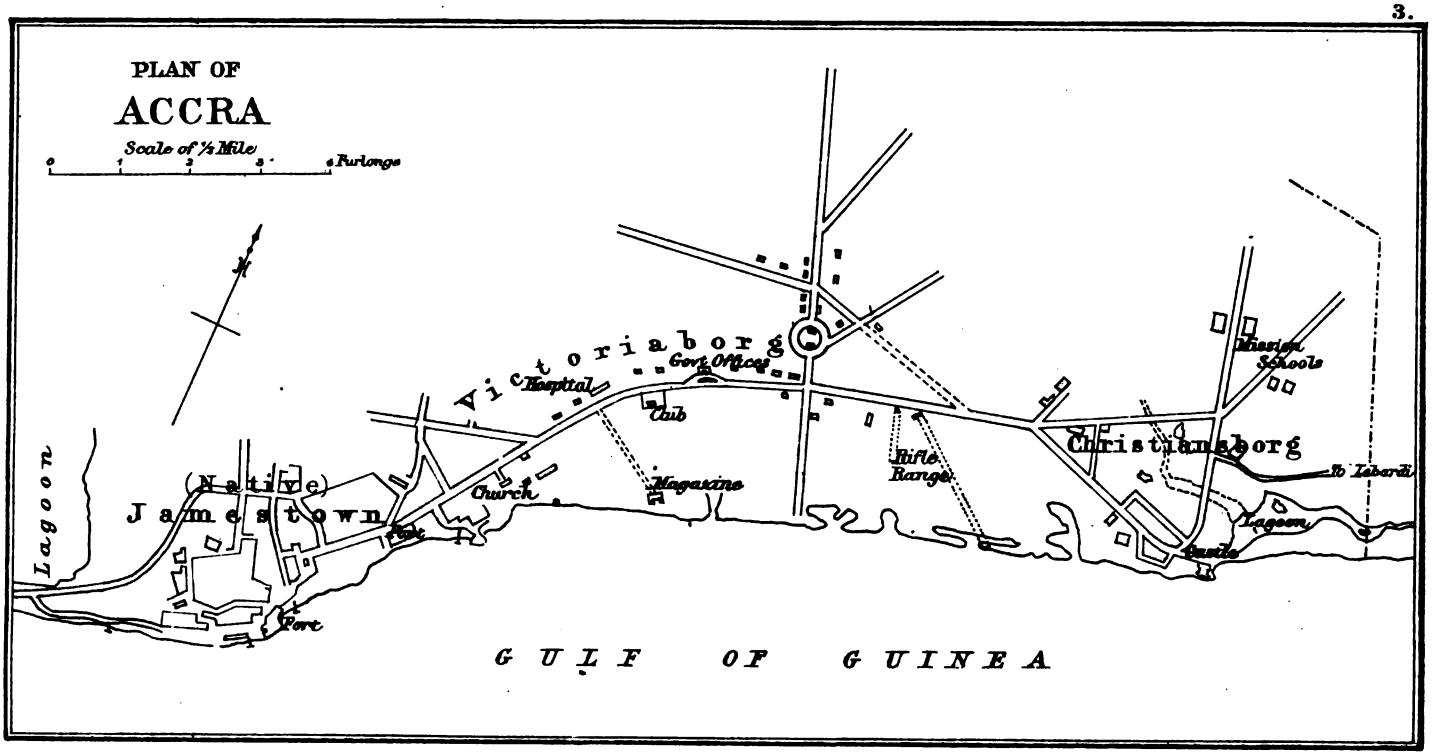

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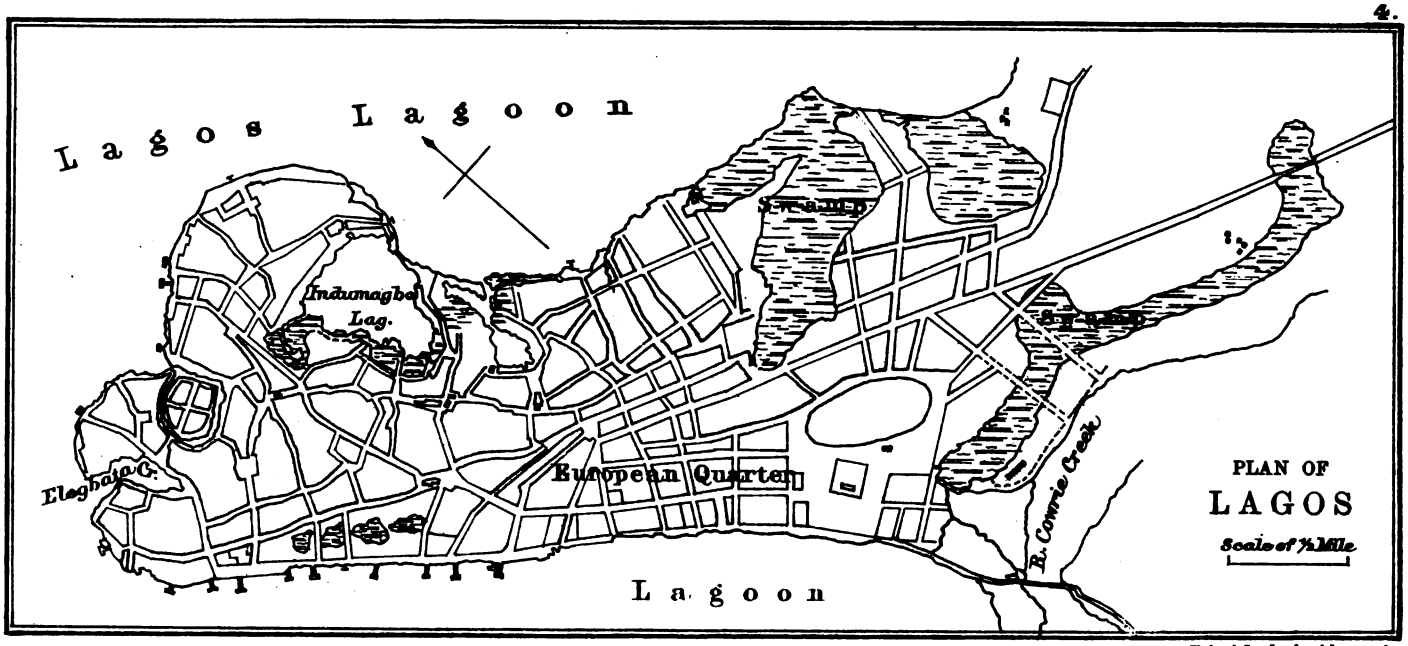

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